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EDITED BY NICHOLAS MURRAY BUTLER

THE TEACHING OF PHYSICS

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THE TEACHING OF PHYSICS

FOR

PURPOSES OF GENERAL EDUCATION

BY

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TO MY

FATHER AND MOTHER

WHOSE WISE AND PRACTICAL INTERPRETATION

OF LIFE

MADE THIS BOOK POSSIBLE

AUTHOR'S PREFACE

ONE of the liveliest themes of present educational discussion is that of the distinction between vocational and cultural work. According to the old ideas, certain subjects are preëminently cultural, while others are distinctly vocational; and in any scheme of general education, the cultural studies must predominate. The present insistent demand for industrial training has brought these ideas into the limelight of investigation, and has divided the forces of education into two parties, which may be called the culturalists and the vocationalists.

This distinction between cultural and vocational seems to be wholly beside the mark in any true system of general education. It owes its origin to the mistaken ideas of the doctrine of formal discipline. This book is an effort to show how, in the case of physics, the two points of view may be amalgamated into one. The fundamental thesis of this union has been stated by President G. Stanley Hall, in his *Educational Problems*, in the following words (Vol. I, p. 614): "In point of fact, we psychologists must make the mortifying con-

fession that we know almost nothing of pure culture values, either what they are or how to acquire them. But we do know that to succeed an individual must put his whole soul into his work, and that the study of even Greek, Latin, and logic in a halt-hearted way is demoralizing and soporific. We know, too, that if most men do not find culture value in their own vocation they will never find it. Anything is cultural that arouses the ambition of young people to do their best; hence whether a topic is cultural or practical depends wholly upon the point of view and the spirit."

The book is divided into three parts. The first of these traces the development of the present situation. The second traces the origin of physics, and seeks to establish its leading characteristics and to define its possibilities as a means of general education. In the third part the purpose of physics teaching is stated, and hints are given as to how this purpose may be attained.

The physics teacher will doubtless find this third part unsatisfactory in that it gives few specific directions as to how to proceed. The reason for this is obvious. Physics teaching has suffered in the past from over-specification. While it is true that young teachers want to be told in detail just what to do, it is equally true that such detailed instructions are a very serious obstacle to effective work. Every successful teacher

must think for himself and adapt his work to his special environment. A detailed specification of just what to do is incompatible with the educational ideas expressed in this book.

In addition to the references given as footnotes to the text, the chapters in Parts II and III are supplied with lists of "collateral reading." In order to make these lists brief, they include in general only references to works published within the past ten or twelve years. Older works are included when they contain material that has not been dealt with more briefly in recent writings.

The author wishes here to express his sense of deep obligation to the many hundred physics teachers who, by correspondence and discussion, have contributed ideas to the New Movement among Physics Teachers, of which this book is the outcome. He also wishes especially to record his obligation to the editor of this series, President Nicholas Murray Butler, of Columbia University, and to Professor J. F. Woodhull, of Teachers College, New York, Professor O. W. Caldwell of the University of Chicago, and Professor G. R. Twiss, of Ohio State University, for their many valuable criticisms and suggestions made while the book was in manuscript and in press.

C. R. MANN.

THE UNIVERSITY OF CHICAGO,
January, 1912.

TABLE OF CONTENTS

CHAPTER IV

PART II

PHYSICS AND DEMOCRATIC EDUCATION

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

PART III

HINTS AT PRACTICAL APPLICATIONS

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER XII

EDITOR'S INTRODUCTION

There is a good deal to be said on the subject of teaching physics in secondary schools and to students of the elements of physical science in colleges, that can properly be said by one who, though not a physicist, is an observer and student of contemporary educational conditions and problems. Certain fundamental principles ought to be assumed.

1. The topics chosen and the method pursued should be determined by the intellectual needs and interests of pupils of secondary school age, and not by some preconceived notion as to what those needs and interests ought to be. College admission tests in physics should be made to depend upon the secondary school teaching of that subject, when properly organized and conducted, and not *vice versa.*

2. The teacher should put out of his mind the thought that each pupil before him is aiming to become a specialist in physical science, or that the study of physics is his main interest in life.

3. Physical science should not be presented as something fixed and definite, whose conclusions are final, but

rather as a division of organized knowledge which is constantly expanding and developing and which has frequently, within historic times, corrected its conclusions in the light of later discoveries. To this end some outline of the history of physical science and of the time and order in which its fundamental laws were discovered and developed should be given to the student. Wherever it is possible to relate the discovery or new application of a physical principle to man's other activities, this should be done in order that the student may be made to feel from the beginning the intimate relation between the laws and phenomena with which physics deals, and other human interests. In other words, the teaching of physics should be humanized.

4. As a farther step in the humanizing of physics teaching, the pupil should be brought to know something of the men whose names are epoch-marking in the history of physical science. Such names as those of Archimedes, Galileo, Newton, Kepler, Gauss, Young, Gay-Lussac, Davy, Faraday, Helmholtz, Kelvin, Torricelli, Ampère, Joule, Mayer, Fresnel, Galvani, Volta, should be familiar to the student, and he should be able to tell something of who these men were, when they lived, and what they did which causes them to be remembered in the history of science.

5. By material drawn from the third book of John Stuart Mill's "Logic," or from Professor Jevons's "Prin-

ciples of Science," the skillful teacher may so interest the student in his laboratory problems that the student will come to understand clearly the significance of the inductive method, of the verification of hypotheses, and of the formulation of so-called laws of nature.

6. The ordinary standards for measuring time, space, weight, and other characteristics, should not be taken for granted, but their origin and history should be made plain and their fundamental principles discussed. Under this head I would include also the thermometer, the barometer, the microscope, the telescope, and the spectroscope.

7. It is difficult for one not himself a physicist to make any profitable suggestions as to the subjects to be selected for presentation to students of physics in secondary schools. In general, however, it may safely be held that these subjects should be those general ones which relate in an elemental or fundamental way to transformations of energy. The tendency observable in many school textbooks to pursue these subjects into very refined and subtle inferences, is to be deprecated. Taught in this way the beginner loses his sense of perspective and physics repels rather than attracts him.

8. Far too much has been made in recent years of accuracy of measurement in the teaching of elementary physics. It is much more important to throw emphasis upon the descriptive aspects of the science and to feed

the growing mind with food that really interests it and helps it to grow, than to pursue the will-o'-the-wisp of training some imaginary power of habitual accuracy. Accurate measurements have their place in the teaching of elementary physics, but that place is a subordinate one. The main task is to teach the constitution and behavior of matter, as it presents itself to the human power of perception, and the laws of motion as these have been observed and deduced, together with the relation of these to man and his activities.

NICHOLAS MURRAY BUTLER.

COLUMBIA UNIVERSITY,
February 1, 1912.

INTRODUCTION

In one of the large high schools of this country, two girls, members of the physics class, were counting the swings of a large pendulum that was suspended in a doorway. On being asked by a visitor what they were doing, they replied, " Measuring the specific gravity of the city." When they were questioned as to whether the result would be expressed in pounds, in cubic yards, in seconds, or in inches, they answered that they did not know.

A student in a college class of physics, having made an experiment intended to measure the acceleration of gravity, brought in the result 967. When asked " 967 what ? " he promptly replied, " Dynes per centimeter per centimeter."

When we consider the importance that is usually attached to the subject of accelerated motion and the amount of time that is generally devoted to it in physics classes, the following experience may prove instructive. At one of the large universities a scholarship examination in physics was given. Twenty-five candidates from fourteen excellent schools presented themselves to

take the test. Since the winning of the scholarship was an honor to the school, as well as a financial reward to the winner, only those pupils whose work in physics in the schools had been most satisfactory entered the competition. One of the questions on the examination paper was this: A block slides without friction down an inclined plane of height 50 cm. and of length, measured along the incline, of 100 cm. What velocity will it have when it reaches the bottom?

Only two of the twenty-five competitors gave the correct solution. One of the pupils answered: —

$$\text{Velocity} = \frac{100}{50}, \text{ or 2 cm. per second.}$$

Another solved it in this way: —

$$W : P :: L : H$$
$$1 : P :: 100 : 5$$
$$P = .5$$

$.5 \times 100 = 50 =$ change in velocity. $50 =$ velocity at the bottom, since a force of .5 will be acting on it through 100 cm.

While the foregoing are, perhaps, extreme cases, every physics teacher knows that answers of this sort are very common — too common to be ignored. Some teachers, to be sure, still comfort themselves with the belief that the same failure to gain clear ideas is equally prevalent

in other studies; and that it is, therefore, a necessary characteristic of a large group of students. But the majority of teachers have now waked up to the fact that such answers are indicative of a condition that needs study and, if possible, correction. The way in which the bibliography of physics teaching has increased during the last decade is ample proof of the fact that a large and continually increasing number of physics teachers are now seriously studying this subject in an effort to find out what is the matter and how better results may be secured.

As is unavoidable at the beginning of the scientific study of any relatively new and very complex situation, many radically different hypotheses have been advanced to explain the phenomenon and aid in obtaining a solution of the problem.[1] Not only are these hypotheses numerous, but the terms in which they are stated are usually not defined with any definiteness. For example, most teachers agree that "physics should be brought close to the daily life of the pupils"; but there are as many different interpretations of this phrase as there are teachers. Each, then, takes his own interpretation

[1] For a summary of some of these suggestions, see Circular II of the New Movement among Physics Teachers, *School Review*, XIV, p. 429; June, 1906; also Symposium on the Purpose of Physics Teaching, *School Science and Mathematics*, VIII, p. 718; IX, pp. 1, 162; 291, Dec., 1908; Jan., Feb., March, 1909.

as complete; and so, while there seems to be agreement, there is no real or helpful solution of the problem. Just exactly what is "physics"? and precisely what does "bringing it close to the lives of the pupils" mean anyhow?

A moment's thought will convince any one that the current definitions of physics, such as "Physics is the science of matter and energy," or "Physics is the science of phenomena," do not assist the teacher who is seriously seeking to find out specifically just what he is trying to bring close to the lives of his pupils. Such definitions may be useful in distinguishing physics from chemistry or biology, but they do not really define *physics* until the more general terms *science*, *matter*, *energy*, etc., have been defined. It is not, for example, particularly helpful to any one to introduce the subject, as one recent text does, by saying: "Physics is the science of matter and energy. In order to understand this definition, we must know what matter is. Nobody knows what matter is."

Spencer's definition of science as "classified knowledge" leads nowhere; not only because it implies an understanding of what knowledge is, but also because, as Dewey has shown,[1] "it is wholly ambiguous. Does it

[1] Dewey, Science as Subject-Matter and as Method, *Science*, Vol. XXXI, p. 125, Jan. 28, 1910.

mean the body of facts, the subject matter? Or does it mean the processes by which something fit to be called knowledge is brought into existence, and order introduced into the flux of experience? That science means both of these things will doubtless be the reply, and rightly. But in order both of time and of importance, science as method precedes science as subject matter. Systematized knowledge is science only because of the care and thoroughness with which it has been sought for, selected, and arranged. Only by pressing the courtesy of language beyond what is decent, can we term such information as is acquired ready-made, without active experimenting and testing, science."

If science is not only "systematized knowledge," but also those "processes by which something fit to be called knowledge is brought into existence," an understanding of the term involves an understanding of those processes. Hence the teacher who would clearly know what he is trying to do is at once launched upon a sea of metaphysics and psychology. He finds himself afloat without a pilot on the ocean of literature that deals with this subject and extends from Aristotle's *Organon* to Dewey's *How We Think*, — an ocean whose shores are lined with shoals of "muddy speculation" and strewn with the wreck of many a cherished system.

But if an understanding of the meaning of science is

so fraught with danger, what shall we say of the terms *matter* and *energy?* Are there any buoys, beacons, or charts that can help to steer a rational course here? And how shall we discover a useful idea of what is meant by the "life of the pupils" to which "physics" must be "brought close"? Is this daily life the daily routine of experiences with materials? Or is it the feelings of the pupils, or their intellectual reaction that is meant? Or is it all of these together? Also, what is the process by which "physics" and "daily life" may be brought together?

The preceding questions have been raised, not for the purpose of introducing a "theoretical" discussion of the teacher's problem, nor yet with any idea of answering them in the following chapters. They are placed here for the purpose of inducing a proper state of humility and open-mindedness on the part of the reader for what follows. These questions have not yet been answered; possibly they never will be. Yet an appreciation of the fact that they are ever with us is a very effective preventive of dogmatism, and the scientific study of them is always of great practical use.

It is the purpose of this book to demonstrate the fact that the study of these insoluble problems of life is of the greatest practical use to the teacher, by pointing out a few of the many cases in which this is true. For this

purpose these problems will be discussed only so far as their discussion seems likely to help teachers in their ever-present, everyday, practical problem of "what shall I do, and how shall I do it?"

THE TEACHING OF PHYSICS

PART I

THE DEVELOPMENT OF THE PRESENT SITUATION

CHAPTER I

The Background

1. **Purpose of the Public High School.** — As a first step in the discussion of the problems roughly sketched in the introduction, it will be well to consider the general development of the public high schools in the United States. Since the growth of physics, like that of every other subject in the high-school course, has been part and parcel of this general development, a preliminary glance at the large outlines of the whole furnishes a background for the better understanding of the parts. This outline will be brief, touching only the high points in the story. Those who wish a more detailed history of the movement for public high schools are referred to the excellent work of E. E. Brown on *The Making of Our Middle Schools* (Longmans, Green, & Co., 1902).

The development of the private secondary schools and academies will not here be considered. The point of view to be maintained throughout is that of the public high school, as first defined by Benjamin Franklin in 1743. In his *Proposals Relating to the Education of the Youth of Pennsylvania*, he says: "As to their studies, it would be well if they could be taught everything that is useful, and everything that is ornamental. But art is long and their time is short. It is therefore proposed, that they learn those things that are likely to be most useful and most ornamental; regard being had to the several professions for which they are intended." [1]

This point of view finds more general definition in the words of Brown: [2] "The high schools, on the other hand, appeal less to imagination and sentiment (than do the academies). Their promoters did not set about doing good to the people, but rather undertook to work with all the people for the common good. Here, too, we touch one of the finest things in all the world, the spirit which draws men together in a common pursuit of the public welfare."

In a word, the high school was founded as part of the new democracy, its special function being that of doing, in the field of education, its full share in solving the hitherto unsolved problems of democracy.

[1] Brown, *Making of Our Middle Schools*, p. 180. [2] *Ibid.*, p. 321.

This being the special function of the public high school, the problem of the physics teacher is not simply that of making his pupils learn that body of organized knowledge now called "physics." It is rather that of finding out how the science of physics may be made to contribute most efficiently to the development of democracy. From this point of view, the teacher is no longer a mere teacher of physics; he is rather one of the large army of those who are laboring for the attainment of the highest possible social efficiency.

2. **Early High Schools.** — Although the need for this sort of public high school was set forth by Benjamin Franklin in 1743, and although his efforts were rewarded by the establishment of the "Public Academy in the City of Philadelphia" in 1751, the real movement for public high schools began with the establishment of the English Classical School in Boston, in 1821. This was followed by the opening of the High School for Boys in New York in 1825; the Central High School in Philadelphia in 1838; and the High School in Baltimore in 1839.[1]

These early high schools were independent schools, each established voluntarily by the city that supported it. In the West, the high schools grew up in general under state systems of education, in which the state re-

[1] Brown, *l.c.*, pp. 297 *sq.*

quired the towns to establish schools in conformity with a system whose ideal was "a more general system of education, ascending in regular gradation from township (district) schools to a state university, wherein tuition shall be gratis and equally open to all."[1] It is this sentiment at the basis of American educational systems that gave in later times such importance to the college entrance requirements. Since the university was regarded as the infallible head of the system, the high schools felt themselves compelled to meet these requirements in order to keep the path open for all from the kindergarten to the university.

In the fifty years, from 1840 to 1890, the number of public high schools gradually increased to 2526, with 202,963 pupils. This was for them a period of struggle for popular recognition. There are records of lawsuits, like the Kalamazoo case in 1872, in which the taxpayers questioned the right of school authorities "to levy taxes upon the general public for the support of what in this state (Michigan) are known as high schools, and to make free by such taxation the instruction of children in other languages than the English." In this case, it was argued that "the general understanding of the people has been such as to require us to regard the instruction in the classics and in the living modern languages in these

[1] Brown, *l.c.*, p. 349.

schools as in the nature not of practical and therefore necessary instruction for the benefit of the people at large, but rather as accomplishments for the few, to be sought after in the main by those best able to pay for them, and to be paid for by those who seek them, and not by general tax." [1]

3. **Expansion of the High School.** — Notwithstanding these objections, the high schools gradually developed in popular favor. Since 1890, the increase in their number has been phenomenal. In 1900 there were more than 6000, with over 530,000 pupils; and in 1910 this number had been increased to 10,213 schools, with 915,061 pupils. In this period the number of pupils increased from 0.36 per cent to 1.03 per cent of the total population of the country. The buildings, grounds, and equipment used by these schools were valued in 1910 at more than $230,000,000; something like $60,-000,000 was spent that year for new buildings and improvements; and the running expenses, while they cannot be accurately given, were certainly not less than $40,000,000 for the year.[2]

Although the United States Bureau of Education began issuing its reports in 1871, the public high schools appear at that time to have been of too little importance

[1] Brown, *l.c.*, p. 357.

[2] Report of the United States Bureau of Education for 1910, II, p. 1132.

to have their statistics included in those reports. These statistics first appear in the report for 1876, and no effort was made to make them complete until 1889. The year 1876 may then be taken as the beginning of that rapid development that has just been noted. Whatever the schools may have been prior to 1876, they seem by that time to have fallen completely under the spell of the idea that the course of study that led to college, as defined by the entrance requirements issued by the colleges, was the highest type of course that they could give. As Brown puts it: "But the high schools gravitated toward the colleges as the academies had done before them. None of the many protests raised against this movement could check it for any length of time. It was, in fact, a thoroughly American movement. It answered to that broad, American logic which maintained that since any youth might rise to the highest offices, every youth should have the opportunity offered to him of rising to the highest education." [1]

Notwithstanding the fact that the high schools were founded largely for the purpose of training those who were not destined for college to greater efficiency in life, there is, with the possible exception of the manual training movement, which began about this time (1879), little evidence that the high schools made any serious

[1] Brown, *l.c.*, p. 373.

efforts to study their magnificent problem of democratic education. Their energies seem to have been exhausted in the process of mere physical growth, and in keeping pace with the expansion of the institutions of higher learning whose feeders they were.

This was a period of great educational activity and expansion on all sides. The colleges, under the pressure of the scientific and commercial activities about them, were adding new subjects to their curricula and expanding their science courses to keep up with the general growth. New courses were introduced; and new degrees, Ph.B., LL.B., S.B., etc., were invented to indicate that these new courses, while meriting recognition, could not possibly give that peculiar "culture" and that formidable "mental discipline" which was supposed to result from an absorbed and exclusive contemplation of antiquity. Engineering and technical schools were founded as separate institutions, in response to the public demand for trained engineers. The students who were going to these schools required a somewhat different preparation than did those going to college; so the high schools were called upon to expand in this direction also.

Finally, the colleges themselves, inspired by the foundation of Johns Hopkins University, began to develop graduate schools, and to expand into universities.

Graduates of American colleges began to appear in large numbers as students in foreign universities. These men returned filled with the spirit of research, and became a source of inspiration to college faculties and students alike. A great wave of enthusiasm for original investigation and the extension of the boundaries of knowledge swept over the country, completely swamping the older ideas of the teaching functions of the colleges. This wave is still upon us, but there are evidences that its force is spent, and that it is beginning to subside.

This wave of enthusiasm for research affected the high schools, too, in a marked way. Teachers came to the schools from the colleges filled with the intoxication of it. Ideas of accurate measurement, rigor, and logical form were carried into the school work with an eagerness on the part of the teachers which was only equaled by the indifference with which the pupils received them. Nevertheless, no one can deny that much good has come to the schools from this whole movement. Some of the effects of it as they appeared in the work in physics will be considered in a later chapter.

Under the circumstances, it is not surprising that the high schools "gravitated toward the colleges." Moreover, the elementary schools were also undergoing such

rapid changes that superintendents of public instruction were absorbed in the work of their reorganization. The kindergarten ideas that were "made in Germany," the Quincy Movement under Colonel Parker, the doctrine of "interest," the findings of "paidology" were all clamoring for recognition. Under this stress of conflicting ideas, the high schools were more or less left by their legal guardians to shift for themselves. The dominant idea of the times was that education was preparation for life; and since preparation for college was regarded as the best possible preparation for life, education was preparation for college. Therefore the high schools, left without the paternal care that might have kept alive the family ties which bound them to the lower grades of public schooling, naturally turned to the college as their guide, philosopher, and friend.

4. **The Committee of Ten.** — The stress and struggle of the conflicting ideas that have just been mentioned soon produced a sort of chaos that was intolerable. This condition led the National Educational Association, in 1892, to appoint its well-known Committee of Ten. The preliminary investigations of this committee brought out the facts that in forty schools, selected as typical: first, the total number of different subjects taught was nearly forty; second, that many of these subjects were taught for such short periods that little train-

ing could be derived from them; and third, that the time allotted to the same subject in different schools differed widely.[1]

The general educational principles advocated in the report of this committee are too well known and too generally accepted to need be more than mentioned here. Since the publication of the report, schools have been and still are trying to correlate studies into well-knit curricula, to secure better trained teachers, to abolish short informational courses, to develop consecutive and more extensive courses, and to compel pupils to divide their work among what the committee called the "four principal fields of knowledge," — languages, mathematics, history, and natural science. In these matters there can be no doubt that the influence of this report has been widespread and effective.

The influence of this report on the simplification and standardization of school administration has also been excellent. The committee adopts "the number four as the standard number of weekly periods" which "will not make it impossible to carry into effect the fundamental conception of all the Conferences; namely, — that all the subjects . . . should be taught consecutively enough and extensively enough to make every subject

[1] Report of the Committee of Ten of the National Educational Association. American Book Co., 1894, pp. 3 *sq*.

yield that training which it is best fitted to yield."[1] This will readily be recognized as the beginning of the "unit" system which is now the basis of high-school administration and of the evaluation of high-school work for purposes of college entrance. All of this is too familiar to make a detailed discussion of it necessary in this brief sketch.

There are two points in the report whose implications have not been generally understood, but which are of importance for the further discussion of the teaching problem. In the first place, the report states (p. 16): "On one very important question of general policy, which affects profoundly the preparation of all school programs, the Committee of Ten and all the Conferences are absolutely unanimous. Among the questions suggested for discussion in each Conference was the following:—

"7. Should the subject be treated differently for pupils who are going to college, for those who are going to a scientific school, and for those who, presumably, are going to neither?

"This question is answered unanimously in the negative by all the Conferences, . . . and the Committee of Ten unanimously agree with the Conferences. Ninety-eight teachers, intimately connected either with the work

[1] Report of the Committee of Ten, p. 41.

of American secondary schools, or with the results of that work as they appear in students who come to college, unanimously declare that every subject that is taught at all in a secondary school should be taught in the same way and to the same extent to every pupil so long as he pursues it, no matter what the probable destination of the pupil may be, or at what point his education is to cease."

Again (p. 51): "The secondary schools of the United States, taken as a whole, do not exist for the purpose of preparing boys and girls for colleges. . . . A secondary school program intended for national use must therefore be made for those children whose education is not to be pursued beyond the secondary school."

In these two passages we have defined the general point of view of the committee; namely, preparation for life is preparation for college. In the light of this statement it is easy to understand why the committee organized only nine conferences, one for "each principal subject which enters into the programs of secondary schools and into the requirements for admission to college." It is also easy to see why "the list of subjects which the conferences deal with as proper for secondary schools is as follows: (1) languages, Latin, Greek, English, German, French; (2) mathematics, algebra, geometry, and trigonometry; (3) general history and

the intensive study of special epochs; (4) natural history, including descriptive astronomy, meteorology, botany, zoölogy, physiology, geology, and ethnology, most of which subjects may be conveniently grouped under the title of physical geography; and (5) physics and chemistry. The Committee of Ten assent to this list, both for what it includes and for what it excludes, with some practical qualifications to be mentioned below." [1]

It seems strange that the list of subjects which the Conferences considered "proper for secondary schools" should coincide with the list of subjects required for admission to college, unless we recognize that the real point of view of the committee, — subconscious and unquestioned, — was that preparation for college was the best possible preparation for life for everybody, whether they went to college or not. This idea seems to have been so woven into the warp and woof of educational thinking at that time, that its color and its fragrance pervaded every garment in which that thinking clothed itself.

The keynote of this type of educational thought can be found in many places in the report. For example, on page 44 we read: "All four programs (suggested by the committee) conform to the general recommenda-

[1] Report of the Committee of Ten, p. 36.

tions of the Conferences; that is, they give time enough to each subject to win from it the kind of *mental training* it is fitted to supply," etc. The subconscious background is thus the doctrine of formal discipline in the form which states that discipline and educational value depend largely on the subject matter, and are inherent in a preëminent degree in those subjects which the Conferences considered to be "proper for secondary schools."

5. **The Committee on College Entrance Requirements.** — The same subconscious background may be discerned even more clearly in the next great step forward in the development of the secondary schools; namely, in the Report of the Committee on College Entrance Requirements, which was presented to the National Educational Association in 1899. The immediate cause of the appointment of this committee was the reading of a paper by Professor William Carey Jones, of the University of California, before the Department of Secondary Education of the National Educational Association at its meeting in Denver in 1895. The title of this paper was *The Prospects of a Federal Educational Union.* The ideas which Professor Jones defended were these:[1] "I plead, in behalf of the systematization of our state school work, (1) for the

[1] N. E. A. Reports, 1895, p. 597.

adoption of an effective, thorough, well-guarded scheme of accrediting, where none now exists; (2) for the strengthening and safeguarding of existing accrediting schemes; (3) for the abandonment of all certificating of schools by colleges and universities, whether open and above board or *sub rosa*, without inspection of the actual work of the school. . . . Finally, I wish to recommend that a committee . . . be organized to devise plans for carrying out such suggestions as I have made, or for otherwise promoting a federation of our educational institutions."

"Discussion of these theses led to a motion for the appointment of a committee to report a plan of action on the basis of Professor Jones's paper. This committee presented the following report:[1] --

"WHEREAS, The most pressing need for higher education in this country is a better understanding between the secondary schools and the colleges and universities in regard to requirement for admission; therefore

"*Resolved*, That the Department of Secondary Education appoint a committee of five, and request the appointment of a similar committee by the Department of Higher Education, the two to compose a committee of conference, whose duty it shall be to report at the next annual meeting a plan for the accomplishment

[1] Report of the Committee on College Entrance Requirements, p. 5.

of this end, so urgently demanded by the interests of higher education."

The committee thus constituted began work in 1896. The first item in its plan of work is this (Report, p. 9): —

"1. The committee should invite the active coöperation of associations already organized for the study of such problems; it should appoint representative subcommittees of specialists interested in the various subjects,— all with a view to the ultimate determination of what should constitute a normal requirement in each of the subjects set for admission to college."

Accordingly, nine subcommittees were organized, one for each of the subjects "set for admission to college"; namely, classical languages, modern languages, history, mathematics, physical geography, chemistry, botany, zoölogy, and physics. It will be noted that none of the technical subjects, like drawing, shop work, domestic science, stenography, etc., appear in this list.

The general committee summed up its conclusions in fourteen resolutions. All of these are worthy of careful study; but two of them are of particular importance for the present discussion. The first of these is (Report, p. 38): —

"XII. *Resolved*, That we recommend that any piece of work *comprehended within the studies included in this report* that has covered at least one year of four periods

a week in a well-equipped secondary school, under competent instruction, should be considered worthy to count toward admission to college."

The italics indicate what has been shown by the subsequent development to have been the important point in this resolution. They indicate the supremacy of the belief that discipline and culture are inherent in certain kinds of subject matter, and are not dependent upon the reaction of the pupils to that subject matter.

The other important resolution of the general committee is this (Report, p. 30): —

"II. *Resolved*, That the teachers in the secondary schools should be college graduates, or have the equivalent of a college education."

The high schools have tried to put this resolution into effect with good success. At present most of the teachers in the high schools are college graduates. This is undoubtedly a mark of excellent progress. It has not, however, been successful in every way; for college graduates have too often proved to be poor teachers, notwithstanding the fact that they were good scholars. The secondary schoolmen are desperately familiar now with the actual results of the combined operation of these two resolutions. These effects, as far as physics is concerned, will be discussed in detail in a subsequent chapter.

Two other points about this report are significant of the school conditions at the time of its publication. The first is that the various sections of the report are signed by seventy-two college men, eleven high-school principals, and twenty-three high-school teachers.

The other is thus expressed in the report (p. 43): "Acting on these lines, the committee has devoted its chief energies, through several years, to securing the formulation of satisfactory courses of study which should serve as *units*, or norms, worthy of national acceptance. . . . These courses of study constitute so many national norms, or *units*, out of which any school may make up as rich a program of studies as its means and facilities permit." It will be noted that the idea of national uniformity of school work, and the notion of measuring that work by "units," here find their full expression.

This report of the Committee on College Entrance Requirements marks the culmination of the supremacy of the ideas on which it is based, — the doctrine of formal discipline and that of preparation for college being the best preparation for life. Since then, these two educational hypotheses have been declining in influence. Their weakness lay in the fact that they failed to take account of the emotional reaction of the pupils to the work and of the value of vocational aims in securing

vital work. They have now been superseded by the theory of motivation and the idea that education is neither preparation for college nor preparation for life, but life itself.

During the period of transition from one set of educational theories to the other, the public high schools have continued to grow in a marvelous way. There are several additional points about them that need to be noted in order to make clear the present conditions which form the background of the problem of physics teaching.

6. The Predominance of Small High Schools. — In the first place, the curricula and syllabi that have been issued, like those in the reports just considered, have generally been framed by college men and principals and teachers from the large high schools, with the needs and possibilities of those schools in mind. Those who have framed these courses seem to have been oblivious to the actual conditions, which are these:[1] In 1910 there were 838 public high schools in cities of 8000 population and over. These schools averaged nineteen teachers to a school, twenty-seven pupils to a teacher, and 516 pupils to a school. The total number of pupils in these large schools are 432,643. This is 47.3 per cent of the total number of pupils (915,061) in all the public high schools in the country.

[1] U. S. Bureau of Education, Report for 1910, II, p. 1131.

In the cities of less than 8000 population, there were 9375 public high schools. These small schools averaged about three teachers to a school, nineteen pupils to a teacher, and fifty-two pupils to a school. The total number of pupils in these schools was 482,418, or 50,000 more than were enrolled in the large schools. This is 52.7 per cent of the total number of pupils in all public high schools.

A moment's consideration will convince any one that the vast majority of the pupils in these small schools, which are located in rural and manufacturing communities and which contain more than half the high-school population, cannot be nourished on a diet of Latin, French, German, algebra, geometry, and the rest of the subjects declared by the Committee of Ten to be "proper for secondary schools." These subjects are foreign to the lives of most of the members of these communities, and hence schooling in these subjects cannot be education for them, since education is life.

On the other hand, college men know very well that some of the best students in college come from these small schools; and the public at large must recognize the fact that many of the most noted and useful of our citizens are reared in these same smaller communities.

It is also clear that only the largest schools — schools with say twenty or more teachers — can support a teacher

who is a specialist in any subject like physics and who teaches nothing else. It is safe to say that in the 10,213 public high schools in the country there are not more than 300 teachers who teach nothing but physics, while 10,000 of those who teach physics in high schools must also teach one or more other subjects. Hence the college demand for a kind of physics that can be taught well only by a specialist in physics is unreasonable. It is a demand that cannot be adequately met in more than one out of every thirty-three schools in the country.

7. **Elimination from High Schools.** — In the second place, there is a great "mortality" in the high schools. In 1910, there were 392,505 pupils in the first year class, 247,936 in the second, 163,176 in the third, and 111,444 in the fourth. Of those in the fourth class, 111,363 graduated, and of these, 37,811 were prepared for college. In order to obtain accurate comparisons, we should, of course, compare the number of graduates in 1910 with the number that entered four years before. Since this number is not on record, we compare the number of graduates with the number that entered in 1907, which was 333,274. It thus appears that about one third of those who entered survived to graduate; and of these survivors, but one third were prepared for college. Hence, only about one ninth of those who enter the public high schools come through prepared for college.

This elimination of pupils from the public high schools has been the subject of much study of late. Prominent among these studies is the investigation by the Massachusetts Commission on Industrial and Technical Education, appointed by the governor in 1904. This report revealed the fact that there were some 25,000 children in the commonwealth of Massachusetts who were between the ages of fourteen and sixteen but who were not enrolled in either the public or the private schools, and who were either not in any gainful occupation, or were employed at the lowest class of unskilled labor, commanding a very low rate of wages, with little or no prospect of advancement.

This report led to the appointment of a state commission to establish industrial schools in the state. Several schools of this type, like the one at New Bedford, have been established independent of the public high schools, whose functions they thus in part assume. The establishment of these schools as separate schools, instead of introducing the industrial work into the public high schools, was due to the fact that the high schools were regarded by the commission as too conservative, and too much given over to teaching only subjects considered "proper for secondary schools," to make it possible to have them introduce the new kind of work promptly and successfully.

8. Recent Tendencies. — The response of the high schools to the present demand for work that shall be significant both to the pupils and to the communities that support the schools is, however, making itself heard in such cases as the new technical high school in Cleveland, the two-year industrial courses in the high schools of Chicago, the experiments at Fitchburg, Mass., and those at Cincinnati. New ideas and a new enthusiasm are thus beginning to take hold of the public high schools, and they now seem to have awakened to the greatness of their problem of democratic education, and to have undertaken experiments which will gradually contribute to its solution.

This awakening of the high schools to their opportunities and their obligations amounts to a complete abandonment of the traditions of following college entrance requirements. What the colleges will do to contribute their full share to the progress now being made by the schools remains to be seen. Harvard has this year adopted a new set of entrance requirements, in which, however, she clings closely to the demand for none but those subjects which the Committee of Ten considered "proper for secondary schools."[1] The University of Chicago has also adopted a new set of

[1] *Science*, Vol. 33, pp. 182, 793; *Educational Review*, Vol. 42, p. 71, June, 1911.

requirements, which allow one third of the pupil's time in the high school to have been spent on any kind of work for which the high school itself gives credit toward its own graduation.[1] A committee of the Department of Secondary Education made a valuable report on this subject, and the National Council of Education devoted one session to its discussion at the meeting of the National Educational Association at San Francisco in 1911.[2] There are many other signs of activity on this subject, and many omens which portend greater freedom for both schools and colleges, and the gradual closing up of the chasm that still yawns too widely between present-day schooling and that education which is life.

[1] *Science*, Vol. 33, p. 945, June 23, 1911; *Educational Review*, Vol. 42, p. 186, September, 1911.

[2] N. E. A. Reports, 1911.

CHAPTER II

Natural Philosophy

9. University Physics. — Physics has been one of the subjects of study in the European Universities almost from their foundation. The scientist of to-day, however, would be loth to recognize the courses that were given then under that name as courses in what is now called physics. For these Middle-Age studies of physics consisted in memorizing Aristotle's speculations on this subject, and in having hair-splitting disputations as to their meanings and their possible implications.

This sort of physics continued to hold a place in the university curriculum as long as Aristotle was the idol and sole authority of those schools. True, we find Roger Bacon objecting to this practice as early as 1276,[1] but his polemics against this sort of "science" and his suggestions for something better fell on deaf ears. The changes which he advocated did not come about until some three centuries had rolled by. The end of the sixteenth century marks the time of the awakening to

[1] Roger Bacon, *Opus Majus*, Edition Jebb, London, 1733, Preface.

the new point of view, which has remained characteristic of the development of physics into its present form. From the time of Galileo (1564–1643), the growth of modern physics has been continuous and closely interwoven with the development of mathematics. This development has determined the nature of the physics instruction in college and university courses.

The fundamental ideas that have characterized this development of university courses in physics have recently been analyzed and explained with great clearness by Bouasse and Duhem.[1] Bouasse shows that the science of physics has always tried to "explain" phenomena; by which is meant "simply and solely to bring each fact under some form."[2] Thus the phenomena of refraction are "explained" when it has been shown that the facts of refraction can be correctly resumed under the form, $\sin i = n \sin r$. The progress of the science of physics has then been effected by first establishing these forms, and then deducing their consequences, discovering their interrelations, and resuming the less general under the more general. For example, the form just given was first established from a study of the facts of refraction, and then later shown to be a special case of the principle of

[1] H. Bouasse, *De la Methode des Sciences*, Paris, Alcan, 1909, pp. 73–110. Duhem, *La Theorie Physique, son Object et sa Structure*, Paris, Chevalier et Revière, 1906.

[2] Bouasse, *l.c.*, p. 91.

least action. In this process, the interest of the modern scientist centers on the second part, namely, the deduction of consequences, and the resumption of the less general under the more general forms.

It is because this university physics has now come to be essentially a study of forms that it is so closely allied to mathematics. Indeed all physicists well know how their science has often been retarded in its progress because the mathematics required had not yet been worked out. Poincaré recognizes this fact when he shows that a law of physics is nothing but a differential equation — a mathematical form;[1] or when he calls the m in the form $f = ma$, a "coefficient in the equation."[2] This matter will be considered more in detail in a later chapter; here it is important to note that this "pure" physics, which has developed in the universities, and which is responsible for the growth of the science, consists essentially in a study of mathematical forms. It postulates the accepted forms, and then spends its energies in deducing their consequences and tracing their implications.

This university science of physics owes its growth and its vitality to the fact that some of the world's greatest geniuses have seen in the problem of establishing suitable

[1] Poincaré, *Science and Hypothesis*, p. 173, New York, The Science Press, 1905.
[2] Poincaré, *l.c.*, p. 76.

forms and tracing their consequences a problem full of significance and one worthy of their utmost efforts. It now stands, in its present highly developed form, as a monument to one of the finest traits of human character, — the disinterested devotion of one's self completely to the accomplishment of a significant task.

10. Natural Philosophy. — Physics in the schools is not so old as physics in the universities. It is impossible to state just when it was introduced into school curricula, but there is record of its having been taught in the academy at Northampton, England, as early as 1729.[1] There were numerous books on natural philosophy intended for school use published during the eighteenth century. One of the most interesting of these is that of James Ferguson, which was published about 1750. This book passed through many editions, was revised in 1805 by Sir David Brewster, and brought out in America in 1806 by Robert Patterson, Professor of Natural Philosophy in the University of Pennsylvania. Mr. Ferguson was a self-educated man, a mechanic by trade, but was elected a member of the Royal Society of London, because of his ability of making abstract philosophical subjects clear.

In his introduction to this book of Ferguson's, Sir David Brewster says: "The chief object of Mr. Fer-

[1] Brown, *Making of Our Middle Schools*, p. 171.

guson's labors was to give a familiar view of physical science and to render it accessible to those who are not accustomed to mathematical investigation. To his labors we must attribute that general diffusion of scientific knowledge among the practical mechanics of this country, which has, in a great measure, banished those antiquated prejudices and erroneous maxims of construction that perpetually mislead the unlettered artist." [1]

In America, Natural Philosophy was one of the subjects studied in the academies from their beginning. In 1754, we find Rev. Wm. Smith teaching "natural and moral philosophy" at the "Publick Academy in the City of Philadelphia," [2] the one founded under the influence of Benjamin Franklin. It was part of the curriculum of the first public high school, the English High in Boston, from the start in 1821. It also appears in the courses of study in the first public high schools in New York in 1825.[3]

This early introduction of natural philosophy into the courses of the academies and the public high schools shows that the purpose for which it was intended was quite different from that which supplied the motive for the university physics. The academies were founded in

[1] Woodhull, The Teaching of Physical Science, *Teachers College Record*, Vol. XI, No. 1, p. 18, January, 1910.

[2] Brown, *Making of Our Middle Schools*, p. 184. [3] *Ibid.*, p. 307.

order that the pupils might learn " those things that are likely to be most useful and most ornamental, regard being had to the several professions for which they were intended."[1] In like manner, the public high schools were established because " no one of the colleges fully answered the public need as regards higher education ; "[2] and because " the commercial activities of the larger towns called for a different kind of training from that offered by the schools designed to prepare for college."[3] Since natural philosophy was taught in both the academies and the public high schools from the beginning, it was evidently recognized as one of the " most useful and most ornamental " of studies, and one well calculated to meet the needs of the people in their struggle for the common good.

But since the colleges did not recognize this subject as one fit to receive credit for college entrance until 1872, it appears that the nature of the instruction in natural philosophy in the academies and high schools differed widely from that demanded by the contemporary college ideas of education. As Benjamin Franklin remarked in 1783, " the Latinists were combined to decry the English schools as useless. It was without example, they said, as indeed they still say, that a school for teaching the vulgar

[1] *Ante*, p. 2. [2] Brown, *l.c.*, p. 280.

[3] *Ibid.*, p. 295.

tongue and sciences in that tongue was ever joined with a college."[1]

11. **Old Texts of Natural Philosophy.** — While opinions may differ as to whether this natural philosophy taught "those things that were most ornamental," all must agree that it taught "those things that were most useful." Of Ferguson's book Sir David Brewster wrote, in 1805: "No book upon the same subject has been so generally read, and so widely circulated, among all ranks of the community. We perceive it in the workshop of every mechanic. We find it transferred into the different encyclopedias which this country has produced, and we may easily trace it in those popular systems of philosophy which have lately appeared."[2]

An inspection of the contents of the book shows us why the knowledge it contained was useful. Sixty-two pages are devoted to machines, and forty pages to pumps. When we recall that at the time of its popularity (1750–1825) machinery was being rapidly introduced into all branches of industry, and that this was the age of the invention of the steam engine, the steamboat, and the locomotive, we may understand why a book of this sort was so popular. It supplied a kind of information for which there was a large and constantly increasing de-

[1] Brown, *l.c.*, p. 190.

[2] Woodhull, *Teaching of Physical Science*, p. 18.

mand. An age of machinery and invention, an era of rapid industrial expansion, was developing, and the classics were unable to meet the demand for information on these subjects as they had met the demand for knowledge of secular things at the time of the Renaissance. A new type of information was needed and demanded by the public; and natural philosophy and the other sciences were invoked to meet the need and supply the demand.

That the natural philosophy of those days satisfactorily met the public demands of the times is evidenced by the number of different textbooks that were published on this subject, and the number of editions through which they passed. The *School Compendium of Experimental Philosophy*, by R. G. Parker, published in 1837, ran through twenty-two editions in its first twelve years. The *System of Natural Philosophy*, by J. L. Comstock, had reached its seventy-third edition in 1846.

The title pages of these old texts bristle with such phrases as "The principles of mechanics, acoustics, optics, are familiarly explained." "The causes of many daily occurring natural phenomena are familiarly explained." Their authors were many-sided men, — often clergymen. Comstock was a physician. Besides his *Natural Philosophy*, he wrote *Introduction to Mineralogy*, *The Elements of Chemistry*, *Introduction to Botany*, *Outlines of Geology*, *Outlines of Physiology*, *Natural History*

of Birds, etc. Quackenbos was the author of *First Lessons in Composition*, *Illustrated History of the United States*, besides having written his *Natural Philosophy.*

The prefaces of these books are filled with statements like these: "The author has sought to render a subject, abstruse in some of its connections, easy of comprehension, by treating it in a clear style, taking its principles one at a time in their natural order, and illustrating them fully with the facts of our daily experience" (Quackenbos, 1859).

"It has been the chief object of the author to make himself understood by those who know nothing of mathematics, and who indeed had no previous knowledge of natural philosophy. The author has also endeavored to illustrate the subjects as much as possible by means of common occurrences, or common things, and in this manner to bring philosophical truths as much as practicable within ordinary requirements" (Comstock, 1846).

"The author has explained some of the most common and interesting phenomena of nature in a manner so familiar and simple, that even young children cannot fail to understand their causes" (Bakewell, 1833).

These few from a multitude of similar statements show the effort that was made to bring the rapidly increasing scientific knowledge of the times home to young people, without trying to force upon them that study of mathe-

matical forms and their interrelations which was characteristic of the university physics. In most of the natural philosophies that were published prior to about 1870, you will search in vain for the expression of principles in algebraic form. The diagrams, too, are almost always pictures of real things, — real pulleys, with a hand pulling the rope; real levers, with a hand pushing on the end. The geometrical diagrams of simple machines, with vectors to represent the forces, were practically unknown.

This point may be made clearer by an example. In Comstock, 1846 edition, the phenomena of falling bodies is treated thus (p. 26): —

"85. If a rock is rolled from a steep mountain, its motion is at first slow and gentle, but as it proceeds downwards, it moves with perpetually increased velocity, seeming to gather fresh speed every moment, until its force is such that every obstacle is overcome; trees and rocks are beat from its path, and its motion does not cease until it has rolled to a great distance on the plain."

Velocity of Falling Bodies

"86. The same principle of increased velocity as bodies descend from a height, is curiously illustrated by pouring molasses or thick sirup from an elevation to the

ground. The bulky stream, of perhaps two inches in diameter, where it leaves the vessel, as it descends, is reduced to the size of a straw, or a knitting needle; but what it wants in bulk is made up in velocity, for the small stream at the ground will fill a vessel just as soon as the large one at the outlet.

"87. For the same reason, a man may leap from a chair without danger, but if he jumps from the housetop, his velocity becomes so much increased, before he reaches the ground, as to endanger his life by the blow. It is found by experiment, that the motion of a falling body is increased, or accelerated, in regular mathematical proportions.

"88. These increased proportions do not depend on the increased weight of the body, because it approaches nearer the center of the earth, but on the constant operation of the force of gravity, which perpetually gives new impulses to the falling body, and increases its velocity.

"89. It has been ascertained by experiment, that a body, falling freely, and without resistance, passes through a distance of sixteen feet and one inch during the first second of time. Leaving out the inch, which is not necessary for our present purpose, the ratio of descent is as follows.

"90. If the height through which a body falls in one second be known, the height which it falls in any

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"90. If the height through which a body falls in one second be known, the height which it falls in any

proposed time may be computed. For since the height is proportional to the square of the time, the height through which it will fall in *two* seconds will be *four* times that which it falls through in *one* second. In *three* seconds it will fall through *nine* times that space; in *four* seconds *sixteen* times that of the first second; in *five* seconds, *twenty-five* times, and so on, in this proportion."

12. Modern High School Physics. — In contrast with this sort of treatment, consider the following explanation of the same subject as given in one of the most used of the modern texts.

"IV. LAWS OF FALLING BODIES

"60. **Uniform Acceleration applied to Falling Bodies.** — Since the acceleration g, due to gravity, is constant for small distances above the earth's surface, the formulæ already obtained for uniformly accelerated motion may be directly applied to falling bodies. The relations between velocity, time, space, and acceleration are expressed by the equations $v = at$ and $s = \frac{1}{2}\,at^2$. Substituting g for a, we have

$$v = gt \qquad (10)$$

and

$$s = \frac{1}{2}\,gt^2. \qquad (11)$$

"If in equation (11) t is made one second, then $s = \frac{1}{2}\,g$; or the space described in the first second, when the

body falls from rest, is half the value of the acceleration of gravity. A body falls 490 cm. the first second; the velocity attained in one second and the acceleration are 980 cm.

"To find the space passed over in any one second, find the space described in t seconds, and in $(t - 1)$ seconds, and subtract the latter from the former. Denoting the distance sought by s',

$$s' = \tfrac{1}{2}\,gt^2 - \tfrac{1}{2}\,g(t - 1)^2 = \tfrac{1}{2}\,g(2\,t - 1). \qquad (12)$$

The distance passed over in any second is equal to half the product of g and one less than double the number of the second. By combining equations (10) and (11) we have

$$v^2 = 2\,gs. \qquad (13)$$

"61. **Laws.** — The laws embodied in the preceding formulæ may be expressed as follows: —

I. *The velocity attained by a falling body is proportional to the time of falling.*

II. *The space described is proportional to the square of the time.*

III. *The acceleration is twice the space through which a heavy body falls in the first second.*"

The former of these quotations is a good sample of the descriptive style that was characteristic of these natural philosophies, and the second shows how the same subject

is treated at present, when the mathematical forms of the university physics have driven out the more tangible and concrete methods of the older books.

The educational merits of this change will be discussed in a later chapter. Attention is drawn to it here for the purpose of emphasizing the points: 1. That natural philosophy was introduced into the schools for a specific purpose, namely, to supply the common people with information about physical phenomena in those schools that were founded for the common good and supported by the public funds. 2. That the natural philosophy, so introduced and so taught, did supply the desired information and did do its part in upbuilding those schools. 3. That natural philosophy had a very different origin from university physics; since the latter consists essentially in studying mathematical forms, in discovering interrelations among these forms, and in deducing and verifying their consequences.

This distinction between natural philosophy and pure physics — this recognition of the fact that there may be a fundamental difference between pure science and science in the service of education — has been clearly recognized by some authors for many years. Thus, Neil Arnott's *Elements of Physics*, published in 1826, contains the following: "Mathematics are at present generally made the beginning of the study, and the reason assigned

is that scarcely any object in physics can be described without referring to quantity or proportion, and therefore, without using mathematical terms. Now this is true; but it is equally true that the mathematical knowledge, acquired by every individual in the common experience of childhood and early youth, is sufficient to enable students to understand all the great laws of nature."[1]

In 1847, John W. Draper, in his *Natural Philosophy for Schools*, says: "There are two different methods in which Natural Philosophy is now taught: (1) as an experimental science; (2) as a branch of mathematics. I believe that the proper course is to teach physical science experimentally first."[2]

Similar statements are found in Hooker's *Natural Philosophy for Schools*, 1863, and elsewhere.[3] Recently a reaction against the study of mathematical forms under the name of physics has taken place, and physics is once more coming to be taught as an experimental and informational science, as it was in the days of natural philosophy. This reaction is not resurrecting the old natural philosophy, with all its acknowledged faults and

[1] Woodhull, Teaching of Physical Science, *Teachers College Record*, Vol. XI, No. 1, January, 1910, p. 17.

[2] Woodhull, *l.c.*, p. 21.

[3] For a fuller discussion of this matter the reader is referred to Woodhull, *l.c.*, pp. 1–82.

shortcomings; it is leading to a new method of treating science for purposes of education. It is hoped that the outlines of this new method, and the principles on which it is based, will become clearer as this discussion progresses.

CHAPTER III

Prescribed Physics

13. Early High School Physics. — Natural philosophy disappeared from the curricula of the schools about the year 1872. Its place has since then been occupied by physics, which achieved the honor of recognition among the subjects worthy of credit for entrance to college that same year. It was at this time that the public high schools began their rapid growth and their equally rapid "gravitation toward the colleges." As has already been noted (p. 20), this "gravitation" continued until 1899, when the schools struck bottom on the Report of the Committee on College Entrance Requirements and rebounded vigorously upward.

A very good picture of the condition of physics in the schools during the early years of this period is given in two special bulletins issued by the United States Bureau of Education; one is Bulletin 6, 1880, compiled by Frank W. Clarke, Professor of Physics at the University of Cincinnati; and the other is Bulletin 7, 1884, compiled by Charles K. Wead, Professor of Physics at the University of Michigan.

The first of these bulletins, that of 1880, contains a summary of the replies received from 175 public high schools and 433 private secondary schools to a questionnaire issued by the Bureau. The questions called for information as to the time of introduction of the course in physics, the number of periods a week devoted to it, the text used, the method of work, the amount of laboratory equipment, the amount of time devoted to laboratory work, whether or not the pupils themselves did any laboratory work, and whether there were class experiments by the teacher or not.

From the tables in which the replies are summarized we learn that there were at that time but four secondary schools in the country, namely, the high schools at Pittsburgh and Worcester, the Punchard Free School at Andover, and the Friends' Select School at Philadelphia, in which a full year's work in physics with laboratory work by the pupils was given. Two public and seven private schools reported shorter courses with laboratory work by the pupils; thirty-eight public and twelve private schools reported a full year's work with experiments by the teachers; fourteen public and ninety-five private schools reported one year or less of textbook work only; and seven public and six private schools reported no physics at all.

The most popular text was Steel's *Fourteen Weeks in*

Physics, which was used in thirty-four public and one hundred and sixteen private schools; next comes Quackenbos, with fifteen public and seventy-one private schools. Norton's *Elements of Natural Philosophy* was used in fifty-eight schools; Wells and Cooley in thirty-eight each, and Avery in thirty-two. Three of the four schools giving a full year of work with laboratory work by the pupils used Rolfe and Gillet. With Steel's *Fourteen Weeks* in one quarter of the schools, it is evident that the "short informational course," to which the committee of ten objected so strongly, was well established by this time (1880).

14. **The Nature of the Course in 1884.** — The second of these bulletins (No. 7, 1884) contains letters from thirty-two secondary schools, seventeen normal schools, and twenty-one colleges. These letters were replies to another series of questions sent out by the Bureau of Education. The questions asked, among other things, for expressions of opinion on the following points: 1. Whether it was desirable to introduce physics (natural philosophy) into the primary and grammar schools, and if so, to what extent. 2. How much time should be given to it in high school, and in which year should it come? 3. Whether physics should be required for entrance to college or not. 4. Whether it is possible to arrange a course that shall satisfy both the college re-

quirement and the needs of the schools. 5. Whether college entrance physics should differ from that for those not going to college. 6. What should be the prevailing character of the high school course, — inductive or deductive, for information or for discipline, whether laboratory work should be included or not, and how much mathematics should be assumed. 7. What are the main reasons for studying physics in secondary schools?

The summaries of the replies received from American schools, to which is added a summary of the contemporary practice and opinion in England, France, and Germany, is worthy of careful study. While there is large divergence of opinion on many points, there is very general agreement that some sort of science should be taught in grammar schools; and that this science should be introduced, not for the sake of information, but for the "mental training and discipline which the pupils acquire through studying the methods whereby the conclusions of physical science have been established."[1] These elementary courses should also be "taught in each kind of school for the benefit of those who will go no farther" (p. 116). Suggestions as to the nature of this elementary work are given on pages 126–128.

As to the time to be devoted to physics in high school, the average of the replies gives about 200 hours as de-

[1] Quoted on p. 115 from British Association Reports for 1871.

sirable. The year in which it should be given is "pretty generally stated to be the third year of the course, apparently because geometry is not usually given before that year. The suggestions in some of the replies that part of the subject be taken in the first year, and the remainder in the third or fourth, deserves careful consideration. The fundamental ideas and ways of looking at the underlying principles of the subject are so new to the student, and need so much time to grow into shape and to have any real meaning, that there is much to be said in favor of spreading the subject over a considerable time" (p. 129).

As to the desirability of requiring physics for entrance to college, the replies are summarized as follows (p. 135): "The study of physics is fitted to give results in mental training that are of very high value and that cannot be given so well by other studies; it is to be considered an essential subject in the secondary schools; in these it will usually be better taught if the college has even the slight supervision over the teaching that a requirement for admission would give, and so this requirement would react to the benefit of the communities where these schools are situated. . . . No more powerful influence could be exerted to improve the quality of the teaching than to make this requirement now under consideration, and to enforce it as rigidly as any other requirement."

It is interesting to note in passing that the replies advocated that "even the slight supervision over the teaching that this requirement would give" should be "enforced as rigidly as any other requirement." Also, at the time of the issue of this bulletin sixteen of the leading colleges already had this requirement; and others followed suit shortly after, until, by the end of the century, most of the colleges required physics for entrance. Since 1900, however, the colleges have been gradually dropping the requirement of physics for entrance, largely because they found that it could not be enforced. The schools did not require it for graduation, and too many students without it applied to colleges for admission.

Most of those who replied to the questionnaire agreed that a course could be planned that would satisfy the requirements both of college entrance and of the schools. What should be the common ground of such a course was left undecided, and the suggestion was made that a committee of college and high school men be appointed by joint action of the National Educational Association and the American Association for the Advancement of Science to settle this question (p. 136).

15. Opinions on the Method of Teaching Physics in 1884. — As to methods of teaching physics, "the weight of opinion is decidedly that at first the teaching should be inductive" (p. 117). The difficulties in the way of

securing inductive teaching are great, because "the teacher has probably known little or nothing of it in his own education, and does not know how to begin. If he has also to teach mathematics, he is especially familiar with deductive methods and their value in training. Again, the progress of the student following the inductive method is so slow, if measured by the usual examination tests, as to discourage a faint heart. . . . The common advocacy of scientific studies for the value of their information makes it more difficult to follow a method in which information is a subordinate end. When pushed to the extreme, the method breaks down utterly; for quantitative experiments are mostly beyond the reach of high school boys, yet very few principles or laws can be established without them" (p. 117).

The inductive method as applied to teaching is thus described (p. 118): "Following the scientific method, we first observe the phenomena sharply, and then seek for a cause or for the law according to which the forces act. A dozen guesses may be made quickly, perhaps to be found insufficient. But if the guess is a definite one, definite conclusions (deductions) can be drawn from it which will lead to new observations or experiments. Perhaps our supposed law is immediately disproved; then we make a new guess, and so continue until one explanation remains which is consistent with all our knowl-

edge and stands all the tests we are able to apply; and now is the time for us to consult the published record of other men's experiments, and in this way learn those facts that are otherwise unattainable by us. If to reason accurately on physical facts be of any value to the student, is not a conclusive disproof of an hypothesis (provided he originated it) more valuable than the incomplete proof with which he must usually remain contented when he learns the accepted hypothesis?"

Two reasons are given for the importance of using this inductive method of teaching, namely (p. 119): 1. "Because, consciously or not, we must use inductive methods all our lives in ways where we cannot avail ourselves of the principle of the division of labor, depending on others. The professional opinions of the physician and lawyer, all our judgments of men, and our opinions on common matters of life must be largely the result of inductive reasoning;" and 2. "Because in the opinion of many teachers, more physics can be taught so as to be remembered in this way than in any other."

The bulletin then shows that, notwithstanding the obstacles in the way of introducing the inductive method, "nearly all the writers of the replies advise it, and one cannot believe that they are advising so unanimously an impracticable scheme. Foreign writers, too, are

very unanimous in urging it. . . . The Socratic method, which is advocated by so many teachers of experience, is really the inductive method put in a form suitable for teaching. The use of textbooks of the ordinary kind, however accurate and clear, is inconsistent with, perhaps almost fatal to, the scientific method in schools" (pp. 119–120).

The discussion of methods of teaching is summed up again on page 130 in these words: "The majority of the replies and the emphatic English opinions already quoted advise that the teaching should be inductive rather than deductive (the statement of principles and laws and of formal definitions coming after the experiments rather than before them and being elicited so far as practicable from the student) and primarily for discipline, since more information can be retained and made useful if the mind be disciplined than if the mere information be the end of the study."

"Laboratory work is favored by the great majority, though sometimes by this expression is evidently meant merely demonstration by the teacher, and sometimes the meaning is doubtful. Unfortunately, few teachers can speak of the results of this kind of teaching, it has been tried so little, except in the normal schools" (p. 130).

"With regard to the amount of mathematical knowl-

edge to be assumed there is the greatest diversity of opinion. The general view may be said to be that the student should have a ready command of arithmetic, of algebra through equations of the second degree, and of elementary geometry. Of these the first is least likely to be secured, for the drill in higher arithmetic appears to be at the expense of that training which is the most useful for its applications in physics, viz. that which enables the pupil to solve easy problems readily and often mentally. Certainly college students show the lack of this kind of training to an unfortunate degree" (p. 131).

As to the importance of the work in the secondary school, the bulletin says, on page 132: "In considering how the study of physics is to be made most useful to the community, both directly and indirectly, it is difficult to overestimate the importance of correct views of the opportunities of the secondary schools. Commissioner Eaton's tables show more than a quarter of a million students in them and only an eighth as many in the colleges. These students are young enough to retain the child's love of nature and of objective teaching; yet experience shows that they are mature enough to profit by a thorough study of this subject, which is one of the very best for inductive training, and even those who are to have further opportunity in college

will derive benefit from having their intellectual eyes opened to the world about them. . . . On the other hand, the lower schools and the country schools draw their teachers largely from the high schools and the academies. So at no point in the whole system is the importance of good, clear, accurate, inspiring training in physics more important than in these secondary schools."

16. The First Syllabus. — Finally the bulletin closes with a list of fundamental experiments in physics, "which may be shown by the teacher, or some of them may be performed by the student in the laboratory. Besides the *topics* involved in this list there are some others of, perhaps, equal importance not so easily illustrated by standard experiments, and every teacher will perform many additional experiments; but this list is drawn up in the hope that the few experiments it contains may everywhere be recognized as fundamental" (p. 146).

This list is here given in full, since it indicates so clearly what was considered fundamental to a course in physics in 1884. A † means fitted for laboratory work; a § involves measurement; an *, more advanced.

†§ Compare and measure lengths, volumes, and masses.
†§ Composition of forces.
Inertia.

†Properties of permanent and temporary magnets.
† Magnetic curves.
† Simple galvanic cell.

†§ Parallel forces.
† Center of gravity.
†§ Lever, inclined plane, &c.
†§ Pendulum.
* Centrifugal action.
†§ Archimedes' principle.
†§ Density and specific gravity.
Capillarity.
†§ Simple barometer.
§* Boyle's law.
Air pump experiments.
Pumps and siphon.
†§ Expansion of liquids and gases.
† Bending of compound bar.
†§ Verify fixed points of thermometer.
† Conduction of heat.
†§ Temperature of mixtures of water.
§* Specific heat of a solid.
†* Latent heat of ice, steam, vapors.
Heat from friction.
* Useful forms of galvanic cells.
† Effects of current on magnetic needle.
† Electro-magnets.
§* Influence of resistance of conductors.
† Chemical effects of current.
* Heating effects of current.
* Induction.
Telegraph and telephone.
† Frictional electricity; two states.
Electrical machine; Leyden jar.
Vibration and production of waves.
†§ Resonance.
† Interference of sound (fork and jar).
§ Monochord.
†§ Photometer.
Reflection; plane and curved mirror.
† Refraction of light.
Dispersion and spectrum.
Total reflection.
†§ Lenses; construction of image.
Combination of colors.

It will be noted that no mention is made of the principle of the conservation of energy, nor are any units mentioned. Even work does not appear, nor are mole-

cules and atoms and the kinetic theory of matter in evidence. There is nothing about acceleration nor about falling bodies nor about Newton's laws of motion. Yet these forty-seven topics were considered enough to make up the essentials of a one-year course in physics in secondary schools.

So much space has been devoted to this bulletin because it advocates so definitely the things which are now so badly missed in the high school courses in physics, — inductive teaching, simple experiments in familiar units, and training in the scientific method of thinking. These ideas found frequent expression at this time (1884); yet in spite of this, they were not followed in the subsequent development of physics teaching. Now there is a general demand for a reorganization of this teaching in conformity with the ideas that were so prominent twenty-five years ago.[1]

[1] For further information on this point, the reader is referred to Report of the Royal Commission on Science Instruction and the Advancement of Science, 9 vols., H. M. Stationery Office, 1871–1875. Reports of the British Association for the Advancement of Science, 1867, pp. xxxix–liv; 1874, p. 71; 1883, p. 309. In the *London Journal of Education*, articles by Worthington, October, 1882; Wormell, January, 1883; Minchin, October, November, 1883; Jas. Ward, November, 1883; in Joseph Payne's *Collected Lectures*, p. 187; J. M. Wilson, *Essays on a Liberal Education;* Report of Committee of the American Association for the Advancement of Science, Proceedings, 1880, pp. 55–63; reprinted in *Popular Science Monthly*, Vol. XXXIII, p. 207.

17. The Harvard Descriptive List. — The next important step in the development of physics teaching was the publication of the well-known Harvard *Descriptive List.* This is a list of laboratory experiments only, and was issued by Harvard College in 1887 to define the laboratory work that was required as part of the course acceptable for admission credit at that institution.

This list contained originally forty-six experiments, any six of which might be omitted. "The choice of experiments required careful consideration. . . . The criterion for this selection was that of practical utility. An attempt was made to bring together such experiments as would have the most frequent and important applications in ordinary life, in the conviction that these would be, on the whole, quite as interesting and important in every other way as any that could be chosen under a different principle of selection." [1]

From the preface to the *Descriptive List* we learn that, "The objects to be sought in the course of experimental physics which this pamphlet describes may be stated thus: first, to train the young student by means of tangible problems requiring him to observe accurately, to attend strictly, and to think clearly; second, to give practice in the methods by which physical facts and laws are discovered; third, to give practical acquaint-

[1] Hall & Bergen, *Textbook of Physics*, p. iv (Holt, 1892).

ance with a considerable number of these facts and laws, with a view to their utility in the thought and actions of educated men."[1]

"With very few exceptions the experiments described will require the student to make *measurements* of some kind. To make such experiments intelligible and profitable, they must, in many cases, be supplemented by other experiments of a less rigorous character, such as are described in the textbooks of Avery, Gage, and various other authors, and many of which are better fitted for exhibition on the lecture table than for performance by each student of the class. . . . The directions given in this pamphlet are in some cases very minute. They are, however, intended to show how the experiments *may* be done, not how they *must* be done. The teacher should decide for himself how closely these directions are to be followed, and should feel at liberty to substitute for the experiments described other experiments covering equally well the same points. . . . This course in all its aspects is intended to occupy the student about five school hours a week, with the usual amount of study out of school, for one year."[2]

"To secure the objects of the course the student during the laboratory exercises is placed, so far as this is practicable, in the attitude of an investigator seeking

[1] Hall & Bergen, *l.c.*, p. vii. [2] *Ibid.*, p. x.

for things unforetold. But this attitude, if rigidly maintained, would be likely to keep him for an absurdly long time upon the study of one set of facts, or induce the habit of loose and hasty generalization. He should be required to work carefully, but not with a higher standard of accuracy than the apparatus and the time at his disposal will warrant. He should not be told what he is expected to see, but he must usually be told in what direction to look. He should be required to draw inferences from his experiments, but the sources of possible or certain error in his work should be pointed out in order that he may be saved from the danger of coming to think that all so-called physical laws are inferred from demonstrations as loose as his own. In fact, the main value of the student's inferences, *in themselves*, is that they will enable him to understand, and without undue stretch of faith to accept, the established conclusions of physicists, and these conclusions should, *in the end*, always be made known to him."[1]

Because of the great influence which this list has exerted on physics teaching, that portion which deals with mechanics will be reprinted in the form in which it appears in the Hall & Bergen *Textbook of Physics*.

1. Breaking strength of a wire.
2. Elasticity, stretching.

[1] Hall & Bergen, *l.c.*, p. xi.

3. Elasticity, bending.
4. Elasticity, twisting.
5. Pressure in a liquid.
6. Compressibility of air.
7. Density.
8. Specific gravity of a solid that will sink in water.
9. Specific gravity of a solid that will float in water.
10. Specific gravity of a liquid.
11. Specific gravity of air; degree of exhaustion.
12. Composition of forces.
13. Coefficient of friction.
14, 15. Parallel forces in one plane.
16. Forces in one plane, but not parallel.
17. Center of gravity; influence of the weight of a lever.
18. Inertia: comparison of masses.
19. Simple pendulum.
20. Action and reaction.
21. The inclined plane; work.

As has been stated, this *Descriptive List* contains only laboratory experiments, with careful directions as to how the experiments *may* be performed. The teacher was left to fill up the rest of his course as best he might. In order to help the teacher in doing this, Hall & Bergen published their *Textbook of Physics* in 1892.

A comparison of this list with that from the Bulletin No. 7, as given above, shows how great an advance has been made in the definiteness of the specification of the experiments. For example, the topic "Inertia" in the first list may mean any number of things; but the

topic "Inertia: comparison of masses," accompanied by full directions as to how to proceed with the experiment, is perfectly definite and a very certain guide to the teacher who is preparing boys to get entrance credit at Harvard. There can be no doubt that this definiteness, both in title and in detail of description of manipulation, of the Harvard *Descriptive List* is one of the chief elements of its power and usefulness. At the time of its publication, teachers of physics were scarce, there were few laboratories and little experience to guide those who wished to introduce this work, so this sort of guidance was essential to the successful establishment of experimental courses in physics.

The influence of the *Descriptive List* on the development of physics teaching in America has been tremendous. It appeared at the psychological moment when the demand for object teaching, which had made its appearance here about 1848, had reached its full force. It exalted this demand for object teaching into a requirement of quantitative laboratory work. It showed teachers and school boards how a laboratory method of teaching could be introduced into the work in physics with the use of materials at hand and with a small outlay for equipment. Its insistence on careful, neat work, and its firm stand for work of a scientific character made its influence on physics teaching a most salutary one for many years.

Some idea of the magnitude and the importance of the change that has come about under the influence of this list may be had by noting that in 1880 there were but four schools in the country giving a full year's work in physics with laboratory work by the pupils.[1] Is there to-day any school in which physics is taught which has not its "physics laboratory" and its modicum of apparatus for laboratory work by the pupils? And who can estimate the effect of this growth of the laboratory method in physics on the similar growth in the other sciences? As the result of this movement, the American public high schools now have laboratories, while the schools in France and Germany are just beginning to secure them.

18. **The Committee of Ten.** — The next important official contribution to the development of physics teaching is the report of the Conference of Physics, Chemistry, and Astronomy to the Committee of Ten.[2] This report recommends (p. 119): "That physics be pursued the last year of the high school course, in order that the pupils should have as much mathematical knowledge as possible to enable them to deal satisfactorily with the subject;" that physics be required for admission to college; that it be taught by "a combination of laboratory work, textbook, and thoroughly didactic instruc-

[1] *Ante*, p. 42. [2] Report of the Committee of Ten, pp. 117-127.

tion;" that the laboratory work should be largely quantitative; and that the aim of the teaching should not be "to make a so-called rediscovery of the laws of physics," but that the pupils should "determine the elasticity of bending wood as to length, breadth, and thickness, and see whether the results agree with the laws."

A list of "experiments that by common consent are used by several authors" is given as suggestive to those teachers who wish to "know the kind and degree of difficulty of experiments suitable for *preparation for admission to college* in physics." This list contains fifty-one experiments. It differs from the Harvard *Descriptive List* in only two important points; namely, it adds, "Find the coördinates of a given curve drawn on coördinate paper, and plot a curve from given coördinates;" and "Relation of the acceleration of falling bodies to the moving force." These two additions, together with the ideas that physics should come in the fourth year in order to insure satisfactory mathematical knowledge, and that the experiments were "suitable for preparation for admission to college," indicate the gravitation toward the university physics and toward the colleges which had taken place in the interval between 1884 and 1893.

19. The National Physics Course. — The Report of the Committee on College Entrance Requirements also

contains a section devoted to physics (pp. 180–182). As regards this section, the general committee says (p. 23): "So far as the reports in our possession have enabled us to do so, we have indicated in some detail what the character of these courses in science should be. Unfortunately, this has been impossible in the cases of physics and zoölogy, and we recommend that the Committee on Physics appointed by the Natural Science Section of the National Educational Association be again requested to supply detailed descriptions of suitable school courses in these sciences."

The general committee further recommends (p. 25): that the physics course in secondary schools occupy not less than one year of daily exercises (one unit); that it include a large amount of laboratory work, mainly quantitative; that the laboratory work occupy approximately one half the time; that the course also include instruction by textbook and lecture, with qualitative experiments by the teacher, all "to the end that the pupil may gain not merely empirical knowledge, but, so far as this may be practicable, a comprehensive and connected view of the most important facts and laws of elementary physics."

When we recall that in the Harvard *Descriptive List* "an attempt was made to bring together such experiments as would have the most frequent and important

applications to ordinary life," the way in which the point of view changed between 1887 and 1899 is at once apparent. It is no longer a question of "Practical acquaintance with these facts and laws, with a view to their utility in the thought and action of *educated men:*"[1] but of a "comprehensive and connected view of the most important facts and laws of elementary *physics*."

Besides the recommendations by the general committee, the report contains (pp. 180–182) an "Outline of Laboratory Work in Physics for Secondary Schools." The origin of this outline is explained in full by its author, Professor E. H. Hall, who was chairman of the physics committee, in his book on the *Teaching of Physics in Secondary Schools* (pp. 327–335).[2] We there read (p. 329): "In this supplementary part of the report the matter relating to physics is little more than the Table of Contents of the Harvard *Descriptive List* and two paragraphs taken, almost without change, from the introduction to that list."

In speaking of this physics section of this report, which, as has just been noted, consists of a list of laboratory experiments only, Professor Hall says:[3] "On the subject of this chapter (Physics in Various Kinds of Sec-

[1] *Ante*, p. 54.

[2] Smith & Hall, *Teaching of Chemistry and Physics in Secondary Schools*, pp. xiii–377 (New York, Longmans, Green, & Co., 1902).

[3] *Ibid.*, p. 327.

ondary Schools) we have something approaching the authority of official utterance in the various publications of the National Educational Association during the past ten or twelve years." Passing over the question as to what may be meant by the "authority of official utterance" in matters educational, we note, as did the general committee,[1] that the aforementioned "authorities" gave no "official utterance" to guide the teacher in his class-room work. Hence the most important function of selecting subject matter other than that of the laboratory, and of choosing an appropriate method of presentation, was left to the textbook writers (not to mention the publishers) and to the lesser organizations of teachers less able to give vent to "official utterances." The way in which the textbooks have used this freedom from the authority that works from above downward will be considered in the next chapter.

Immediately after the adoption of the Report of the Committee on College Entrance Requirements, including, as it did, the Harvard *Descriptive List*, now backed up by the "authority of official utterance," several apparatus companies put on the market complete outfits capable of "doing" all the experiments in this list. The companies advertised these outfits widely, stating that they were especially designed to enable the pupils

[1] *Ante*, p. 61.

to perform all the experiments required by what the companies called the "National Physics Course." These outfits were sold extensively throughout the country, and exerted a powerful influence toward fixing the nature of the course and that of each experiment, and toward encouraging schools to introduce laboratory work of the kind specified, because they furnished an easy means of doing so, and one which did not require the teacher to be too much of a specialist in physics.

How firmly this "National Physics Course" became intrenched was shown by an investigation conducted by a committee of the Central Association of Science and Mathematics Teachers in 1906.[1] The committee sent out a questionnaire containing a list of one hundred and one experiments used in secondary schools. Each teacher was asked to indicate those experiments which he regarded as essential to the course, and also those which he had found most successful with the students. Two hundred and seventy-five replies were received from teachers in all parts of the country. Forty-seven experiments were voted essential to the course by a majority of those who replied; and twenty-nine of these were declared to be essential by two thirds of those who replied. Of the forty-seven experiments chosen by

[1] A New Movement among Physics Teachers, Circular II, *School Review*, Vol. XIV, p. 429, June, 1906.

the majority, thirty-six are contained in the Harvard list as it appeared in the Report of the Committee on College Entrance Requirements; and of the twenty-nine chosen by two thirds of the teachers voting, twenty-six are contained in that list.

There can be no doubt, as has been shown abundantly above, that the Harvard *Descriptive List* was, at the time of its publication (1887) and for a number of years after that, a very useful document. It helped to create a demand for laboratory work, which has resulted in the establishment of high school laboratories. It supplied teachers and schools with valuable suggestions as to ways and means of equipping laboratories at a cost that was not prohibitive. Its insistence upon quantitative work aroused teachers to an appreciation of the need and the value of making measurements. When, however, it became clothed with the "authority of official utterance," and was baptized "National Physics Course" by the apparatus dealers, its vitality was gone. It has now become an institutionalized form, which, like all such forms, first blocks the way of progress, and then fades away.

20. The New York State Syllabus. — The failure of the Committee on College Entrance Requirements to outline the subject matter for the class work in physics soon led to trouble in those places where the work of the

secondary school was tested by examinations set by an authority outside the school. It is clear that in places where such examinations are considered desirable, there must be some sort of an agreement between the examining bodies and the teachers as to the nature of the work and the nature of the examination. It was, doubtless, to meet this need that the New York State Department of Education issued its *Topical Syllabus in Physics* in 1905.

This syllabus contains 260 topics, and is a model of what is usually called logical order. It was revised in 1910 by the addition of a few more topics. When we recall that a unit in physics is defined as 120 hours of class work, we see that this syllabus allows the teacher less than half an hour to teach each topic, including demonstrations, laboratory exercises, quizzes, etc.

In like manner, the College Entrance Examination Board has issued a new syllabus as a basis for conducting its examinations.[1] This syllabus contains 170 topics, and is an abridgment of the New York State Syllabus. It is an interesting document because it was compiled by a committee consisting of six secondary school teachers

[1] Definition of the Requirement in Physics, *School Science and Mathematics*, Vol. IX, p. 572, June, 1909; Vol. X, p. 34, January, 1910; *Educational Review*, Vol. 37, p. 532, May, 1909; Vol. 38, p. 150, September, 1909.

of physics, without any help from the colleges. This syllabus is thus a fairly accurate presentation of the consensus of present opinion among secondary school men as to what constitutes a reasonable ground for college entrance examinations in physics.

21. **The North-Central Syllabus.** — One other topical syllabus of importance has recently been issued (1907) by the North Central Association of Colleges and Secondary Schools.[1] This syllabus was not designed to define the limits of examinations, for practically no examinations are given by authorities outside the school in the North Central States. It was compiled by the National Commission on the Teaching of Physics[2] by a method of exclusion, and contains only those topics to which no objection was made by any one of the fifty-five members of that commission. It contains eighty-one topics, and represents, because of its method of compilation, the consensus of opinion concerning the essentials of a high school course in physics at the present time. Because of the small number of topics, it allows large possibilities for the variation of courses to suit local needs, yet retains sufficient uniformity to furnish a basis for college entrance examinations and subsequent

[1] Proceedings of the North Central Association, 1910, p. 37; *School Science and Mathematics*, Vol. VIII, p. 522, June, 1908.

[2] *School Review*, Vol XIV, p. 658, November, 1906.

work in college for those who go on to a further study of physics.

This syllabus is significant, not so much because of what it contains, as because of what it omits. The development of physics in the universities had carried into the secondary school work a large amount of abstract work with absolute units, accelerated motion, kinetic theory of gases, and the like. These are entirely omitted from this syllabus. The topics are stated in rather general terms, yet terms which have a specific meaning to physics teachers now. Its treatment of mechanics is as follows: —

1. Weight, center of gravity.
2. Density.
3. Parallelogram of forces.
4. Atmospheric pressure, barometer.
5. Boyle's law.
6. Pressure due to gravity in liquids with a free surface; varying depth, density, and shape of vessel.
7. Buoyancy, Archimedes' principle.
8. Pascal's law; hydraulic press.
9. Work as force times distance, and its measurement in foot pounds and gram centimeters.
10. Energy measured by work.
11. Law of machines; work obtained not greater than work put in; efficiency.
12. Inclined plane.
13. Pulleys; wheel and axle.
14. Measurement of moments by force $\times$ arm; levers.

In regard to quantitative work, the introduction to this syllabus says: " At least twenty of the laboratory experiments should involve numerical work and the determination of such quantitative relations as may be expressed in whole numbers. Such quantitative work should aim to foster the habit of thinking quantitatively, but should not attempt to verify laws with minute accuracy nor to determine known physical constants with elaborate apparatus. . . . The class work should aim to build up in the student's mind clear concepts of physical terms and quantities, and an intuitive appreciation of the general principles which make up the syllabus. He must be trained in the use of those principles in the solution of simple, practical, concrete numerical problems."[1]

22. **Uses and Abuses of Syllabi.** — Whenever a syllabus is regarded by a teacher as merely suggestive, but not binding, its effect may be very good. Unfortunately, recent practice has shown that this is not likely to be the case when the syllabus is enforced by an authority outside the school. Under this system, teachers know well that it is necessary that their pupils make good showings at examination time. Hence the teacher feels compelled to " cover " every topic in the syllabus at any cost. Under this system educational experimen-

[1] Proceedings of the North Central Association, 1910, p. 38.

tation is at a standstill, and the adaptation of the course to local needs is well nigh impossible.

The workings of this system of examinations by authorities outside the school is thus described by the Committee on Curricula of Secondary Schools of the British Association for the Advancement of Science in their report to that association at its Dublin meeting in 1908 (p. 534): "We are struck with the unanimity shown by our correspondents concerning the influence of external examinations on the teaching of science. This influence is found to be harmful. The harm is produced partly by having to work along the lines of too rigid a syllabus, but chiefly by the fact that science is intended to teach *principles*, while the examination asks for *details*. A boy may have derived the full benefit from a course of science lessons without remembering the experiments therein; for the examination, however, he has not to repeat these experiments; he has to memorize them, and to study how to reproduce what he remembers in the approved examination style. Anything farther from true scientific method could not possibly be conceived.

"Working on the lines of a prescribed syllabus limits the teacher's initiative and discourages research methods. The syllabus in nearly all cases prescribes too much for the majority of schools; and, therefore, too much is attempted in the schools. This prevents sufficient atten-

tion to the scientific method of inquiry. All the school work in science should be imbued with the aim of cultivating an appreciation of and familiarity with scientific method. Examinations will continue to impede this aim in so far as the school work is forced to conform to the examinations rather than *vice versa*."

The results of enforcing syllabi by external examinations are the same in America as in England. While this practice may yield excellent results in the humanities, it is perfectly clear, for the reasons just given, that it has been fatal to the development of vital teaching of science.

Prior to the publication of its syllabus, the College Entrance Examination Board exercised a similar unfortunate influence in schools where one or more pupils were being prepared for these examinations. The questions of the past examinations were then the laws of the Medes and the Persians for the teacher, and he was very prone to cram his pupils on these stale questions until those who were going to the examination could recite the whole list by heart. The new syllabus is still too new to trace its effects; but since the number of topics in it is only 170, there is some chance of teaching it all with some degree of efficiency, and at the same time of adapting the course to local needs.

In the West, college demands are enforced entirely

by the inspection and accrediting system. This system is no less effective a means of keeping the schools in line than is the examination system. Since the Western colleges have, until recently, dreaded being charged with "lowering standards" (standards being undefined), they have maintained the same sort of work that has been demanded by the College Entrance Examination Board. This condition is now rapidly passing away. The colleges in the North Central Association agree to admit without examination pupils from schools that live up to the rules and definitions of that body. Since the definition of the physics unit that is now in use by that association has but eighty-one topics in its syllabus, the teachers of the middle West are free to make experiments in teaching within very wide limits. The results of this freedom are beginning to appear in some excellent experiments like those in the Englewood High School, Chicago,[1] those in the high school at Menomonie, Wis., and elsewhere.

[1] Tower, *School Science and Mathematics*, Vol. XI, p. 1, January, 1911.

CHAPTER IV

Textbooks Old and New

23. The Problem not yet Solved. — In the preceding chapter attention has been called to the demand that physics be taught inductively, in order that the pupil might learn to think scientifically. In order to secure this sort of training, the teachers of the past generation fought for laboratories and equipment; and "when the battle was on, men lost their heads — men must lose their heads in order to fight. We thought that if we could get laboratories, the problems of education would be solved."[1]

"Now science is recognized; we have laboratories everywhere, and laboratory training is regarded as indispensable. It is therefore fitting to ask: What are we doing with our facilities? What results are we obtaining? Do the results obtained justify the equipment and time devoted to scientific study? I am not qualified to answer these questions for the schools; but, speaking for the colleges, I may say that in my opinion the results

[1] Remsen, *School Science and Mathematics*, Vol. IX, p. 281, March, 1909.

are frequently quite unsatisfactory. The reason is that we have not yet learned how to deal with the subject. It is not hard to teach chemists chemistry, but it is very hard to teach beginners something that is worth while about chemistry in one year."[1]

The reason why the mere acquisition of laboratories and the introduction of laboratory work by the pupils have not solved the problem of training the pupils in scientific thinking is thus given by Dewey:[2] "A student may acquire laboratory methods as so much isolated and final stuff, just as he may so acquire material from a textbook. One's mental attitude is not necessarily changed just because he engages in certain physical manipulations and handles certain tools and materials. Many a student has acquired dexterity and skill in laboratory methods without its ever occurring to him that they have anything to do with constructing beliefs that are alone worthy of the title of knowledge. To do certain things, to learn certain modes of procedure, are to him just a part of the subject matter to be acquired; they belong, say, to chemistry, just as do the symbols H_2SO_4 or the atomic theory. They are part of the arcana in process of revelation to him. In order to proceed in the mystery one has, of course, to master

[1] Remsen, *l.c.*, p. 282.

[2] Dewey, *Science*, Vol. XXX, p. 125, Jan. 28, 1910.

its ritual. And how easily the laboratory becomes liturgical! In short, it is a problem to conduct matters so that the technical methods employed in a subject shall become conscious instrumentalities of realizing the meaning of knowledge — what is required in the way of thinking and of search for evidence before anything passes from the realm of opinion, guesswork, and dogma into that of knowledge. Yet unless this perception accrues, we can hardly claim that an individual has been instructed in science. This problem of turning laboratory technique to intellectual account is even more pressing than that of utilization of information derived from books. Almost every teacher has had drummed into him the inadequacy of mere book instruction, but the conscience of most is quite at peace if only pupils are put through some laboratory exercises. Is not this the path of experiment and induction by which science develops? Communication of science as subject matter has so far outrun in education the construction of a scientific habit of mind that to some extent the natural common sense of mankind has been interfered with to its detriment."

In like vein, W. S. Franklin says, "My experience is, most emphatically, that a student may measure a thing and know nothing at all about it; and I believe that the present high school courses in elementary physics, in

which quantitative laboratory work is so strongly emphasized, are altogether bad." [1]

24. **The Method of the Texts; Definitions.** — In order to test the statements that the mere acquisition of laboratories has not solved the problems of education, and that the value of the training derived from a study of science depends entirely on how the work, both in the classroom and in the laboratory, is done, we will try to find out how this work has been and is done. Unfortunately, it is now impossible to visit the classes of bygone years; so we shall study the texts and manuals used, and endeavor thus to get some information as to methods of instruction. As the majority of teachers follow the books rather closely, we shall be able in this way to gain considerable insight into the methods of teaching used in the past and at the present time, and thus to form some idea as to the educational value of the work. In this chapter only the date of the sources of the quotations used will be given, because these quotations are typical of the system of teaching, and the questions raised are pertinent to that system rather than to any particular text or author.

If you open almost any of the textbooks of physics or of natural philosophy, you will find something of this sort (1837): —

[1] Franklin, Proc. of the N. Y. State Science Teachers' Asso., 1907, p. 92.

"1. Natural philosophy is the science which treats of the powers and properties of natural bodies, their mutual action on one another, and the laws and operations of the material world.

"2. Some of the principal branches of Natural Philosophy are: Mechanics, Pneumatics, Hydrostatics, Hydraulics, Acoustics, Pyronomics, Optics, Astronomy, Electricity, Galvanism, Magnetism, Electromagnetism, and Magneto-Electricity.

"3. Matter is the general name of everything that occupies space or has figure, form, or extension.

"4. There are seven essential properties belonging to all matter, namely: 1. Impenetrability, 2. Extension, 3. Figure, 4. Divisibility, 5. Indestructibility, 6. Inertia, and 7. Attraction."

Then follow attempts at defining these terms, impenetrability, extension, figure, and the rest.

Or again (1878): —

"1. What is Science? — Science is classified knowledge.

"A person may live for years among plants, have acquired a vast store of information concerning them, know that this one grows only in wet ground, that another is valuable for such and such an end, and that a third has certain form, size, and color. This general information may be valuable, but it is only when the facts are classified, and the plants grouped in their respective

orders, genera, and species, that the knowledge becomes entitled to the name of botany, a science.

"2. What is Matter? — Matter is anything that occupies space or 'takes up room.'

"There are many realities that are not forms of matter. Mind, truth, and hope do not occupy space; the earth and the raindrop do.

"3. Divisions of Matter. — Matter may be considered as existing in masses, molecules, and atoms.

"A clear apprehension of the meaning of these terms is essential to a full understanding of the definition of Physics, as well as of much else that follows.

"4. What is a Mass? — A mass is any quantity of matter that is composed of molecules.

"The word 'molar' is used to describe such a collection of molecules."

Then follows what are supposed to be definitions of molecule, atom, forms of attraction, forms of motion, physical science, physical change, and physics.

Again (1901): —

"1. Matter. — It is only a colorless definition of matter to say that it occupies space. It is better described by its properties, to which the next chapter is devoted. Science is not yet able to tell what matter is, but the balance has demonstrated that it is invariable in amount, whatever form it may be made to assume.

"A limited portion of matter is a body, and different kinds of matter, having distinct properties, are called substances. A gold coin, a drop of water, air inclosed in a vessel, are bodies. Each is also a substance, since it has properties distinct from the others.

"2. Energy. — It is a fact of common observation that a body in motion can impart motion to another body, either by direct collision or otherwise. It is customary to say in such a case that the first body does work on the second. One body may also impart motion to another by virtue of its relative position. Thus, the weight of a clock when wound up gives motion to the pendulum and keeps it swinging against the resistance of the air and of friction. Whenever one body changes the motion or relative position of another, against a resistance opposing the change, the first body is said to do work on the second. Energy may be defined as the capacity of doing work. It is a grand doctrine of modern science that the energy of the physical universe is conserved, or is invariable in amount. This principle of the Conservation of Energy will become clearer when we have studied the various forms which energy may assume, and its conversion from one of these forms into another.

"3. Physics. — In its most general aspect Physics may be defined as the science of matter and energy."

The next topics, discussed in a similar way, are: 4. Physical Phenomena, Theory, Law; 5. Experiment; 6. The Properties of Matter; 7. Extension; 8. Measurement of Extension; 9. Mass and Weight; 10. Measurements of Mass; 11. Impenetrability; 12. Porosity; 13. Inertia; etc.

Again (1906): —

"1. Physics Defined. — Physics treats of energy and matter and their relations to each other in so far as there is no change in the identity of the matter.

"Energy may be provisionally defined as that which may cause a change in matter, and matter as that which occupies space.

"2. Body and Substance. — A body is a distinct portion of matter, as a nail, a hammer, a car, a ship, etc.

"A substance is a particular kind of matter, as iron, sugar, water, oxygen, etc.

"3. Fundamental Quantities in Physics. — In dealing with energy and matter, the fundamental quantities are length, mass, and time. To construct an exact science it is necessary to make accurate measurements, to do which requires the adoption of units of measurement.

"4. Measurement. — To measure any quantity is to determine its value in terms of a definite portion of the same kind of quantity; the definite portion thus employed is called a unit of that quantity."

The topics that follow are: 5. Two Systems of Units; 6. Units of Length; 7. Equivalents of Linear Units; 8. Units of Mass; 9. Equivalents of Units of Mass; 10. Units of Time, etc. After defining the other kinds of units and the methods of using them, there follow the topics: 21. Variation; 22. Kinds of Quantities; 23. Ratio; 24. Proportion; etc.

Once more (1908): —

"1. Physics is the science of matter and energy. Each of these is as important as the other. We know nothing of matter except through the agency of energy and nothing of energy except through the agency of matter.

"Physics is one of the exact sciences. In its investigations constant use is made of mathematics, and the most refined and accurate instruments known to man are often required. It may be said to be a science of measurements.

"2. Unit of Measure. — Every measurement is a comparison. The thing with which the measured quantity is compared is the unit of measure. If you measure the length of the table by your pencil, you may say the table is ten pencils long. You have compared the length of the table with that of the pencil, and the length of the pencil is the unit of measure. A unit is the first essential in all measurements. The magnitude of any quantity is the ratio of that quantity to the unit."

This introduction is followed by 3. Standard and Legal Units; 4. Systems of Units; 5. Fundamental and Derived Units; 6. Absolute Units; 7. The Unit of Length; 8. Definition of Mass; 9. The Unit of Mass; 10. Weight, etc.

This almost universal habit of beginning the treatment of physics with a series of definitions is easily traceable to Newton, whose *Principia* begins, as is well known, with definitions (so called) of Quantity of Matter, Quantity of Motion, *vis insita*, *vis impressa*, *vis centripita*, etc.

It is now a well-known fact that Newton adopted this method of presenting his researches in order to make discussion of the results impossible. Some of his earlier publications on optics had been criticized by Hooke and others, and he had been drawn into quite a controversy about them. This was distasteful to Newton, so he drew up his *Principia* in the deductive form used by Euclid, a form which admits of no discussion, once the definitions and axioms are accepted.[1] It was doubtless for this reason that he calls his laws of motion laws or *axioms* of motion.

Notwithstanding this fact, writers of physics texts have, with rare exceptions, felt that the subject must be opened with definitions. One recent text (1902) says: "The essential nature of energy is unknown. We can

[1] Block, *La Philosophie de Newton*, p. 129. Paris, Alcan, 1908.

measure its quantity, but we know nothing of its descriptive quantities. It may be provisionally defined as the capacity for doing work." Here, although the futility of attempting a descriptive definition is not only recognized but expressed, the defining habit was too strong to be resisted. And the student must learn this *provisional definition*, although both author and teacher know it has no meaning.

It is worth noting, in passing, that the sort of topics whose definition is attempted in the texts has changed. The older texts "defined" matter and the properties of matter; the newer ones define "physics," "matter," "energy," and then pass on to units and methods of measurements. This change is typical of the change that took place when natural philosophy was converted into physics.

25. General Statements. — Besides this general characteristic of texts of beginning with definitions, there are several other traits, which are common to almost all the books, and the justification of which, from the point of view of teaching, needs discussion. The first of these characteristics is shown in the following quotations (1864): —

"Liquids transmit pressure equally in all directions. This remarkable property constitutes a very characteristic distinction between solids and liquids; since solids

transmit pressure only in one direction, viz. in the line of the direction of the force acting upon them, while liquids press equally in all directions, upward, downward, and sideways. The effects of the practical application of this principle are so remarkable that it has been called the Hydrostatic Paradox, since the weight or force of one pound, applied through the medium of an extended surface of some liquid, may be made to produce a pressure of hundreds or even thousands of pounds. Thus, in Figure 105, *A* and *a* are two cylinders containing water connected by a pipe," etc.

(1888) "**Liquids influenced by External Pressure Only.** (1) **Pascal's Law.** — Liquids transmit pressure equally in all directions, and this acts at right angles upon the surface pressed. The transmission of pressure by liquids under some circumstances is more perfect than by solids. Let a straight tube, *AB*, be filled with a cylinder of lead, and a piston be fitted to the end of the tube," etc.

(1901) "**Laws of Fluids.** — There are three fundamental principles of pressure in fluids which may be called the laws of fluids: —

"I. Fluid pressure is normal to any surface on which it acts.

"II. Fluid pressure at a point in a fluid at rest is of the same intensity in all directions.

"III. Fluid pressure, neglecting the weight of the fluid, is the same at all points throughout the mass of the fluid.

"Fluid pressure is measured by the force exerted per unit area.

"*Illustrations.* — Experiment. — Fit accurately to the mouth of a thin-walled pint bottle a close-grained cork. Fill the bottle full of water and then force in the cork by pressure, using a lever if necessary. The bottle will probably break. Explain. How could the bursting force be estimated?"

(1908) "**Transmission of Pressure.** — Pascal's law is as follows: Pressure exerted at any place upon a fluid inclosed in a vessel is transmitted undiminished in all directions to every part of the interior of the vessel.

"Imagine a box to be filled with wheat or with smooth bright bicycle balls. Because the kernels of wheat or balls slide over one another easily the contents of the box will exert pressure on its sides as well as on its bottom," etc.

This form of presentation has been very common. It is very evident why inductive teaching and training in scientific thinking is impossible with this kind of treatment. Yet it is so much a habit of the adult mind to think from generals to particulars, that we find it cropping out all through books that profess to proceed

from particulars to generals. Thus one of the recent texts (1910), in which the presentation is mostly from particular to general, we find immediately after a definition of "energy" and a discussion of the change of "potential" into "kinetic" energy, the following statement: "Although energy is passing continually through transformations and is being transferred from one body to another around us on every hand, no one has ever been able to prove that even the smallest portion can be created or destroyed. The inference is, therefore, that *the same quantity of energy is present in the universe to-day as existed ages ago*; *i.e.* that the quantity of energy present in the universe remains constant. This is known as the *Law of the Conservation of Energy*."

26. **Experiments Precede.** — It is gratifying to note that several of the most recent texts (1908–1911) are decidedly inductive in their method of presentation. They teach Pascal's Principles, for example, as follows (1910): —

"**Transmission of Pressure — Pascal's Law.** — Let a vessel of the form shown in (1), Fig. 78, be filled with water to the point *a*. A pressure will be exerted on every square centimeter of area depending on the depth of that area. The force exerted upward against the shaded area AB, assumed to be 100 square centimeters, is 100 h grams, if h is the depth of the water in the tube. This

force is entirely independent of the area of the portion of the vessel at *a*. Let this area be 1 square centimeter. Now, if 1 cubic centimeter of water is poured into the vessel, the depth of the liquid is increased 1 centimeter, and the depth of the surface AB becomes $h + 1$ centimeters. The force now exerted against AB is $100\,(h + 1)$ grams, *i.e.* each square centimeter of AB receives an additional force of 1 gram. Hence, the force exerted on a unit area at *a* is transmitted to every unit area within the vessel."

This is followed by applications to the hydraulic press, city water supply, water motors, hydraulic elevators, etc. It will be noted that the principle is nominally derived from a concrete experience, namely, the discussion of the distribution of pressure of the water in "a vessel" whose picture is shown, in which the "force exerted upward against the *shaded area* is 100 h grams," etc. There is no previous discussion of experiences with water pressures to define a problem for the student or to create in him a need or even a desire to know how the pressure is transmitted. All the applications are discussed after the principle has been established from the concrete (?) laboratory or lecture experiment.

This method of proceeding from the concrete to the abstract, or from the particular to the general, is the

one usually followed in those books that try to proceed inductively. Its justification from the point of view of educational value is another of the topics that needs further discussion.

27. Generalized Bodies. — Another characteristic of all books in elementary physics is illustrated in the following statements (1906): "If *a body* possesses energy, it obtained it from *some* other body because the second body performed a certain amount of work upon the first body, and in performing the work lost as much energy as the first body received. *No* body can exert force unless it possesses energy. If *a body* possesses energy because of *some* position or condition it has acquired by virtue of work having been done upon it, *this* energy is called potential energy."

This generalized form of statement and this use of the indefinite article with the word "body" is certainly confusing to young people. They find it hard to visualize "*a* force of 10,000 dynes acting on *a* body," while it is easy for them to grasp what is meant by "a boy pulling a sling shot with a force of three pounds."

The problems in the newer books are particular sinners in this matter, especially since the introduction of the absolute unit of force and the mathematical treatment of accelerated motion. It then became difficult, if not impossible, to find real problems with which to

"train the mind" in the use of the *dyne* and the *centimeter per second per second*; therefore disembodied problems, such as "A force of 5000 dynes acts for 10 seconds on a mass of 250 grams, what momentum is imparted to the body?" had to be invented.

In one recent text (1910), which states in the preface that "The exercises throughout the book have been selected from concrete cases," there appear a number of "concrete" exercises like this: "What is the velocity of *a body* having uniformly accelerated motion at the beginning of the *t* th second?" "*A body* whose mass is 20 grams is given an acceleration of 45 cm. per second per second. What is the required force?" "What acceleration will be given to *a mass* of 25 grams by a constant force of 500 dynes?" etc. This generalized form of thinking is so usual to physics teachers, that we find it hard to realize how vague it is apt to make the subject to beginners.

28. General Theories Precede. — Another characteristic of many of the texts is illustrated by the following quotations, which are the paragraphs introducing the subjects of light and heat in the books from which they are taken. Thus (1901): —

"Light, as distinguished from the sensation of seeing, is a periodic or undulatory disturbance in a medium which is assumed to exist everywhere in space, even

penetrating between the molecules of ordinary matter. This medium is known as the ether. Light waves do not consist of alternate condensations and rarefactions, as in sound, but of periodic, transverse disturbances. These disturbances are probably not transverse movements of the ether itself, but transverse alterations in the electrical and magnetic condition of the ether. But whatever may be the nature of the medium, light is a wave motion in it, and the vibrations are transverse."

Again (1906): —

"Heat is molecular kinetic energy, *i.e.* the energy of the vibrating molecules of matter. When a bullet strikes an iron target, its motion is suddenly stopped and it becomes hot. The kinetic energy of the mass disappears, being changed into kinetic energy of the molecules. The kinetic theory of matter affirms that the molecules of a body are in motion. A body possesses energy owing to this molecular motion; the more rapidly the molecules move, the greater is their energy and the hotter is the body."

Once again (1910): —

"Just as sound is defined as undulations in the air, or some other medium, that produce the sensation that we call 'sound,' so light, in the same sense, consists of undulations or waves in the ether that produce the sensation which we often call by the name 'light.' Not

all ether waves can be regarded as light waves, since not all affect the organ of sight; but all ether waves, from the longest to the shortest, transfer energy, and therefore may properly be classed as carriers of radiant energy.

"Ether fills all interstellar space as well as the spaces between the molecules in bodies of matter. The ether is also of extreme rareness, or tenuity, since planets passing through it suffer no appreciable retardation in their orbits. Ether waves possess several well-known characteristics. They are transverse waves and are propagated with a definite speed, and this speed becomes less when they pass through matter such as glass, air, water, etc."

This peculiar mixture of fact and assumption in passages of this sort deserves careful analysis. What sort of an idea does a student get when he is told, at the time of his first contact with the subject, that light *is* an undulatory motion in a medium which is *assumed?* And what problem is left for the student to solve in the subject of heat when he is informed at the outset that heat *is* molecular kinetic energy? Is there any motive left for further study, when every possible question he might like to ask is thus definitely settled in advance, and every hypothesis of his own making is thus nipped in the bud?

This kind of treatment suggests the idea that the darky preacher must have been studying this sort of material while preparing the sermon which began thus: "Brederen, dis mawnin' I'se gwine ter define fer you the indefinable; I'se gwine ter explain ter you the inexplicable; and I'se gwine ter unscrew fer you the inscrutable."

29. Laboratory Manuals. — As far as method of treatment goes, the laboratory manuals are much more nearly alike than are the texts. Each topic is treated under the heads: Purpose, Apparatus, Procedure, Computation, Conclusion, or their equivalents, in strictly logical order. The instructions are usually so detailed as to make it well-nigh impossible for the pupil to go wrong or to raise questions.

The older manuals made much of "verification" of laws. In the newer manuals the purpose of the experiment is usually stated: "To find the specific gravity of a liquid," "To study the conditions for equilibrium of three concurrent forces," "To measure E. M. F. of cells by a potentiometer," and so on.

The purpose of the laboratory work is differently stated by different authors. This purpose can, however, be already seen by noting a series of experiments like the following (1908): "Measure the resistance of *a* wire by the method of substitution. Find the resistance

of a cell by the method of reduced deflection. Find the resistance of a cell by means of a voltmeter and an ammeter. Measure electrical resistance by the fall of potential method. Measure electrical resistance (of what?) by means of a Wheatstone bridge. Find the relative resistance of different metals, referred to copper."

Here we have six experiments in the measurement of the electrical resistance of various things by different methods. Some of the recent manuals have as many as nine experiments in measuring the specific gravity of various substances by different methods. Are so many experiments on one topic necessary in order to give the topic a concrete basis for its comprehension by the pupil, or are the experiments intended really to familiarize the pupil with the technique of laboratory work? If it is the former, would not the result be better obtained if the resistances measured were those of familiar things, — incandescent lamps of various kinds, electric bells with the wires to be used in their circuits, telegraph sounders, and the like, — instead of *a wire* detached from life; and if only one, or at the most, two methods of measurement were used? In other words, might not the study of the relative resistances of 4, 8, 16, and 32 candle-power carbon incandescent lamps, and of 40, 60, and 100-watt tungsten lamps on the same circuit,

lead to a better comprehension of the importance and the function of electrical resistance in everyday affairs, than does the measurement of the resistance of never so many *detached* wires by various methods never met with outside of a laboratory?

30. Conclusions. — These quotations have been given in order to emphasize certain characteristics of the large majority of physics textbooks, both old and new. These characteristics are: —

1. The general prevalence of definitions and general statements of principles at the beginning of each topic. This method of presentation has given place to some extent in some of the most recent books to one in which the topics are introduced by laboratory or lecture experiments. In a few cases we find topics introduced by common experiences.

2. The abstract nature of the treatment caused by discussing not *this* or *that* particular thing, but *a* body, *a* mass, *a* wire.

3. The introduction of general theories, like the kinetic theory of matter or the undulatory theory of light, at the beginning of the treatment of these subjects. This leads to that peculiar mixture of fact and assumption that has been noted.

4. The predominance in the modern laboratory manuals of the demand for training in laboratory technique

and methods of making refined measurements, wholly detached from the problems likely to arise in daily life.

It is, perhaps, because of these characteristics that the books under consideration have been and still are called "texts." For a clergyman preaching to adult minds, a general statement, or a "text," is an appropriate introduction for a Sunday sermon. With full propriety he can set up his "text" as a general thesis to be defended or expounded, and then proceed to its exposition. But is this method of treatment the most effective one to be found when the purpose is, not to instruct adults concerning the divine truths of revelation, but to train young minds into scientific methods of thinking? This question is a complex and a difficult one. Before it can be answered, we shall have to consider more in detail several of the factors on which the answer depends.

PART II

PHYSICS AND DEMOCRATIC EDUCATION

CHAPTER V

THE PEDIGREE OF PHYSICS

31. **Plato.** — As a first step toward finding answers to the questions raised in the last chapter, it will be well to consider how physical science has come to be what it is, and what it is at present. It will, of course, be impossible within the limits of one chapter to do more than point out what seem to have been the leading factors in its development, and what its present leading characteristics are. Moreover, the factors and characteristics that are treated in what follow are those which throw light on the use of physical science as a means of education. No attempt is here made to define science as a whole, nor to trace its development in detail.

In order to form a clear idea of what physical science is really like, we must disembarrass ourselves of the tradition that its foundations were laid by Plato and Aristotle. No one questions the fact that these intellectual giants of antiquity made large and important

contributions to the development of modern civilization; nor will any one deny that it is possible to quote from their writings vague statements which may be interpreted in such a way as to give credence to the claim that these philosophers "anticipated" many of the notions of modern physics. But when we remember that science consists not only of a mass of organized knowledge, but also of the method by which that organized knowledge was secured, we must question the validity of the claim that physical science is directly indebted to any large extent to the philosophers of classical antiquity.

It is, fortunately, not necessary to discuss in detail the philosophical systems of the Greeks in order to see that their methods of dealing with natural phenomena were totally different from those now in use. No one can study any of the many histories of philosophy without having this point made clear. It will, however, help us to understand modern physics if we briefly recall the leading characteristics of the teachings of Plato and of Aristotle.

Plato's system of philosophy was intended to give a solution of the problem: how is it possible for numerous individuals, each having an independent power of thinking, to agree on anything? His solution of this problem is that each individual possesses "innate ideas," which

are derived from a previous state of existence, and which are absolutely fixed and perfect. This body of innate ideas make up the "real" world, while the world of phenomena is but an imperfect and fleeting symbol or appearance of this real world of immutable celestial ideas. It is the presence of these immutable ideas in the soul of each and every individual that makes agreement among several apparently independent individuals possible.

Thus when a customer went to a shoemaker to get a pair of shoes, the two "understand each other because, although they are different 'organisms,' 'minds,' or 'souls,' yet both have a 'recollection' or 'reminiscence' of an eternal or 'celestial' shoe which each has apprehended in a previous supernal existence, and of which all 'terrestrial' shoes are 'imitations' or 'shadows.'"[1]

Since Plato's real world consists of a body of absolutely fixed ideas, it is a perfectly rigid or static world. Human efforts can produce no change in it. Motion, the central fact of modern science, is but an appearance. Therefore, there is nothing left for the philosopher but to *know* this world of ideas. Knowledge of it is obtained by *thinking* about these innate ideas, and by losing one's self in "celestial contemplation" of them. Thus, thinking is

[1] Moore, *Pragmatism and its Critics*, p. 34 (University of Chicago Press, 1910).

the only function in our experience whose activity is supposed to be consistent with the completeness and perfection of that world.

"Thus began that ever widening psychological breach between thought and the other activities. Thought soon becomes a form or side or phase of experience alongside of other forms, having its own special function, namely, the cognition of the absolute world, which it exercises under its own laws. . . . Social agreement and co-operation at bottom must now mean agreement and coöperation in regaining or losing the celestial vision. Our impulses, instincts, desires, emotions, volitions, are all mere symptoms of the distortion of the celestial vision, or of attempts at its restoration." [1]

Plato's *Republic* is a good example of this Platonic thinking. In this "the family, no less than the individual, is sacrificed to the state; the state itself being an abstraction. Like the utopists of modern days, Plato has developed an *à priori* theory of what the state should be, and by this theory all human feelings are to be neglected; instead of developing a theory *à posteriori*, *i.e.* from an investigation into the nature of human wants and feelings. . . . Aristotle saw where the initial weakness lay — in the disregard of the individual and his needs." [2]

[1] Moore, *l.c.*, p. 41.

[2] Lewes, *History of Philosophy*, Vol. I, p. 269 (London, Longmans, Green, & Co., 3d ed., 1867).

This philosophy of Plato's has exercised and still exercises a very powerful influence in the world. His exaltation of the activity of thinking above all other activities is doubtless one of the responsible causes for the present belief that intellectual training and "mental discipline" constitute an education. His doctrine that truth is an eternally fixed idea apart from and above human experience, and that truth may be secured by contemplation of his immutable "real" world of ideas, is distinctly at variance with the present ideas of science. Platonic love is generally recognized as an idea that runs counter to deep-seated traits of human nature, while this Platonic thought still flourishes; yet both neglect the profound fact that humanity possesses emotions and feelings as well as powers of thought. How much of our present educational system is the result of Platonic thought, derived from a contemplation of fixed and abstract ideas of what children should be? And how much is based on a scientific study of what children actually are? This is a problem of rich content for some historian of education.

32. **Aristotle.** — Aristotle's physics is thus characterized by the most recent critic of it:[1] "It is interesting in this respect to compare the Aristotelian theory of

[1] Henri Bergson, *Creative Evolution*, Engl. Tr. by Mitchell, p. 228 (New York, Holt, 1911).

the fall of bodies with the explanation furnished by Galileo. Aristotle is concerned solely with the concepts 'high' and 'low,' 'own proper place' as distinguished from 'place occupied,' 'natural movement' and 'forced movement'; the physical law in virtue of which the stone falls expresses for him that the stone regains the 'natural place' of all stones, to wit, the earth. The stone, in his view, is not quite stone, so long as it is not in its normal place; in falling back into this place it aims at completing itself, like a living being that grows, thus realizing fully the essence of the genus stone. . . . We know what kind of physics grew out of this, and how, for having believed in a science unique and final, embracing the totality of the real and at one with the absolute, the ancients were confined, in fact, to a more or less clumsy interpretation of the physical in terms of the vital. . . . The ancients did not ask why nature submits to laws, but why it is ordered according to genera."

Again (p. 330): "The ancient science thinks it knows its object sufficiently when it has noted of it some privileged moments (as the stone when at rest on the earth), whereas modern science considers the object at any moment whatever. . . . The forms or ideas of Plato or of Aristotle correspond to salient moments in the history of things — those in general that have been fixed by lan-

guage. . . . We may say, then, that our physics differs from that of the ancients chiefly by the indefinite breaking up of time."

From the point of view of modern science, the leading characteristics of the Greek philosophies were: 1. Their taking one particular aspect of a phenomenon as alone characteristic and descriptive of it; whence 2. Their classification of phenomena into genera and species in accordance with the aspects selected as characteristic; 3. Their insistence upon the finality and immutability of innate ideas. Because these fundamental, general characteristics are so different from those of modern physics, it seems justifiable to conclude that modern physics is not directly descended from the Greek philosophy.

This conclusion is further strengthened by the fact that during the Middle Ages, one of the greatest stumbling blocks to the progress of modern physics was the scholastic philosophy, which developed from hair-splitting discussions of the meaning of the writings of Aristotle.

33. **Art Precedes Science.** — If, then, physical science is not the outcome of the Greek philosophy, whence did it come? The answer to this question is contained in the recognized fact that the manual arts have always developed before science. As has often been pointed out, the Egyptians could not have built the pyramids unless

they were acquainted with the use of the "mechanical powers." Yet the scientific treatment of these "powers" began with Archimedes' treatment of the lever, and may be regarded as not yet having attained its utmost perfection. The Israelites knew that they could not make "bricks without straw"; yet it is only recently that the "scientific" reason for this has been evolved. The steam engine was a highly perfected machine before thermodynamics became a science; and music was a well-developed art before Helmholtz wrote his *Sensations of Tone*.

The detailed study of the history of science from this point of view is a fascinating occupation, but beyond the scope of this book. We find the savage pursuing a crude science in his efforts to control his physical environment and to foresee the results that might be expected to follow from various combinations of circumstances. Impelled by a very real need — hunger — we may imagine him thinking over the various facts in his possession regarding food; then selecting fish as the means of meeting his need with the "least action"; then making a plan, *i.e.* framing an hypothesis as to how to secure the fish; and finally putting his hypothesis to the test of experiment. If he caught the fish and his hypothesis was verified, we can imagine him telling his comrades that he had discovered the "truth"

about fishing; or, at least, he might claim that he had found an "expedient" way of thinking about fish and the other related factors in his physical world.

The high thinkers among the Greeks and Romans did not apply this method of solving the problems of their physical surroundings very extensively, because it was not their function in society to take part in the industrial activities of the times. These functions belonged to the slaves — the philosophers were there to "just think" Platonic thought.

The Romans, however, must have solved many political problems in the scientific way. Their civil law was constantly changing to meet the exigencies of new situations, and their magnificent achievements in political organization could hardly have been possible if they had not been skillful in finding the "most expedient" methods of dealing with concrete political and social situations.

34. **Development of Industry.** — For science, the most important fact from the Middle Ages is the gradual development of industry first by serfs, then by freedmen. Industry, not politics, was one of the potent factors that brought about the change from serfs to freedmen. When overproduction began, trade and commerce were instituted. Since those were times of uncertainty, the men interested in industry and trade organized the guilds

and then the towns for the mutual protection of common interests, — the beginning of the modern spirit of co-operation. Then feudal lords and the fiefs were swallowed up in the formation of kingdoms, which were larger units offering better protection for the interests of industry and commerce. Here again, the industrial and commercial interests were powerful factors in bringing about the change.

According to Adams:[1] "The various lines of growth which began an increasing activity from the Crusades, and which led out from the Middle Ages into modern history, were dependent for their accelerated motion, for immense reënforcement, if not for actual beginning, upon the rapidly developing commercial activities of the time."

Again:[2] "The increase of commerce and the development of cities becomes the rise of the third estate into a position of power. This is a fact of utmost importance in the general history of civilization, because this progress once begun in reality never ceased; and in our own time is characterized by the practical absorption, economically and politically, of the other two estates into the third. At the beginning of the Middle Ages, the first estate — the clergy — and the second estate — the nobles —

[1] Adams, *Civilization during the Middle Ages*, p. 280 (New York, Scribner, 1900). [2] *Ibid.*, p. 305.

controlled everything. With the growth of commerce this began to be changed. The ready money of the merchant was as effective a weapon as the sword of the noble or the spiritual arms of the church. Speedily also the men of the cities began to seize upon one of the weapons which had been the exclusive possession of the church and one of the main sources of its power — knowledge and intellectual training. With these two weapons — wealth and knowledge — the third estate forced its way into influence."

Again:[1] "The kings sought only political power and did not care to preserve serfdom, until, too late, they saw that complete industrial freedom tended toward a democracy that would be as inimical to royalty as the feudal aristocracy had been. Among the townsmen there was no strong desire for municipal liberty, provided the economic arrangements could be adapted to the needs of commerce without political independence. Self-government was only an expedient to which the merchants had been compelled to resort in order to free themselves from the sovereignty of the lords. It is a fallacy to read back into the consciousness of the burghers who were struggling for the right of self-government a desire for independence for its own sake. In the be-

[1] Forrest, *Development of Western Civilization*, p. 212 (University of Chicago Press, 1907).

ginning independence was desired for practical reasons only."

In its earlier stages the industrial movement was a necessity in order to supply the necessities of life and the muniments of war. In the course of time, as political conditions became more stable, the human needs which it was called upon to satisfy became more diversified; the intellectual and artistic cravings of the mind began to demand satisfaction, and the technique of industry had to be enriched to meet the situation. Cathedrals and castles were built, Gothic architecture was developed, and ornaments in bronze and stone were wrought out with a mechanical skill that has not been surpassed.

It is not difficult to see why industry and commerce were the chief lines along which marked progress was made in the Middle Ages. During the thousand years that intervened between the fall of the Roman Empire and the publication of Copernicus's epoch-making work (1543), all abstract thinking was controlled from Rome. The doctrines of the church demanded an ascetic and devout life here, and a blind faith in the doctrine of salvation by faith alone and that of the infallibility of the Pope. Industry and commerce were the only fields of activity in which no Roman doctrine blocked the way of progress, and which were even encouraged by the

church in its teachings concerning the worth of the individual and the dignity of labor. But in spite of its efforts to suppress thought, the church finally started, unwittingly, to be sure, the new age, when it called upon Christendom to unite in the Crusades and drive the infidel from the Holy Sepulchre.

The Crusades opened the eyes of Europe to the fact that there were many interesting things to do in this world beside contemplating a problematic future life. During the Crusades (1092–1200) the industrial and commercial classes rose rapidly in importance because of the business which the Crusades made. In the so-called Renaissance we see the interest in worldly things breaking forth with passionate eagerness, leading men to seek information about this world and its people, even in the classics. This eagerness for information about the world made necessary the invention of printing and the establishment of the first newspaper (1505); it inspired the voyages of discovery by Columbus, Magellan, and the rest ; and the returns that came from this invention and these voyages created new enthusiasm for the life here below and an increased desire for a better knowledge of nature and her ways.

35. **The Method of Industry.** — For the student of the history of science, there are several important points to be noted in this development. In the first place,

the process by which it was accomplished was this: some human need, desire, longing, or aspiration made itself felt, whereby a real problem was defined, — a problem that would not lie down and keep quiet until the need that called it into existence was satisfied. The solution was found by first studying concrete things, then forming a plan of action which seemed expedient under the circumstances, and then testing the plan by a process of adaptation of means to end, of approximation, and of experimentation.

In the second place, the solution of one problem reacted to stimulate new needs and desires; and these, in turn, defined new, more refined, and more difficult problems. Thus it has gone from one need to one problem to new needs to more problems, thence to additional higher needs, whence more problems; and so on, *ad infinitum*. Because of this the process was a vital one, capable of growth.

In the third place, the success of this great upward movement of industry and commerce was due to the fact that they were able to " deliver the goods " that were needed to satisfy the human desires that called them into being. They were able to produce tangible results which everybody wanted and could comprehend, and whose " expediency " no one could deny.

In the fourth place the discoveries and successes

achieved by this method of solving problems were so concrete, so impelling, so undeniable, that even the infallible church had to succumb. Because of this, large bodies of men came to rely on the method as the one method that was capable of yielding dependable and demonstrable results, so that it came into common use on a large scale among the commercial and industrial classes. When large bodies of men had thus become accustomed to thinking in this way, the time was ripe for the extension of the method to the solution of more general and more abstract problems. Then it was that modern physics proper began. The fact that physics did not begin until commerce and industry were well developed is one of the fundamentally important facts to remember when studying the problem of how to use physics for purposes of general education.

As a further example, consider how the Crusades created a demand for a means of travel to the Holy Land. The first Crusade, 1097, went entirely by land, while the third, 1187, went largely by sea. Shipbuilding had expanded in the interim to meet the demand, and it has flourished ever since because it produced the tangible results that the people wanted. And who can estimate the indebtedness of the present civilization to this same industry?

Every one will agree to the fact that the shipbuilding

industry has contributed largely to the growth of civilization. Still, there are many who will say: "Yes, but it was the 'idea' of ship that created the industry, and this idea is 'innate' in mankind. Has not Charon been ferrying souls across the Styx from all eternity?" If this is true, why were not the first ships electric-lighted ocean greyhounds? No, it was reserved for men to discover by a long process of trial and error, — of adaptation, approximation, and experiment, — what the "most expedient" form of ship was. And this "form" is not immutable, but changes and develops to keep pace with the industrial and commercial needs on the one hand and human desire and fancy on the other.

No one at present can fail to recognize the fact that we are now living in an industrial and commercial age — for the industrial movement, which began when it became socially permissible for a freeman to engage in these activities, has continued to advance with a positive acceleration ever since. It has supplied the concrete foundation of our present social order and was a veritable father to modern physics. The fact that physics is a direct lineal descendant from industry has important bearings on the pedagogical problem.

36. **Germanic Industry**. — This industrial and commercial development is the work of the Germanic races; and its marvelous success is due to the method

of thinking which they alone have known how to use with all its vigor. Men have always solved the problems that nature thrusts upon them by a more or less crude use of the method. But it was reserved for the Germanic races to apply it with success to industry, science, and abstract thinking. This was because the Germanic thinking differed from that of classical antiquity in several fundamental points. These points are thus explained by Chamberlain:[1] "The Greek made few observations, and those never without bias; he was not endowed with the long-enduring patience which is necessary in order to make any great discovery."

"The whole secret of making discoveries lies in letting nature speak. To do this requires great self-control, a characteristic which the Greeks did not possess. The weight of their genius lay in their creative imagination; the weight of ours lies in our receptivity."

"The great work of laborious discovery has a deadly enemy: the know-it-all. With Aristotle a problem is hardly stated before its answer is given. . . . We see, therefore, why the work of discovery was so long in beginning."

"All systematization and theorizing is a fitting to-

[1] Chamberlain, *Die Grundlagen des Neunzehnten Jahrhunderts*, pp. 760 *sq.* (4th ed., München, Bruchman, 1903). An English translation has just appeared (New York, Lane, 1911).

gether, an adaptation, which, while as accurate as possible, is never wholly without error. The Greek did not know this. Unexcelled as a creator of form, he demanded perfection and complete rounding out in science as well; thereby he sealed for himself the door by which men may enter into a knowledge of nature. . . . We Germans are engineers rather than architects. We also know how to create forms; yet our aim is not the beauty of the thing formed, nor yet a form perfect and giving final satisfaction to the human mind, but rather the establishment of a proviso which makes possible the collection of new data and thereby a wider knowledge. . . . Our scientific process is a denial of the absolute."

The Germanic attitude toward nature may then be characterized as one of desire to learn and possess; it lays weight on the utility of the result in satisfying human needs, and is content to use approximations and provisional forms, provided only that they enable us to accomplish this purpose. Germanic science seeks to discover laws, — that is, constant relations between variable quantities, — and it does this by experiment and approximation. It is, therefore, not absolute, but relative; not perfect, but approximate; not dogmatic, but open-minded.

What Aristotle would call the "quintessence" of this great industrial development has been pointed out by

Carlyle in his *Review of the Corn Law Rhymes* in the following words:[1] "Nay it appears to us as if in this humble Chant of the Village Patriarch might be traced rudiments of a truly great idea; great, though all undeveloped. The Rhapsody of 'Enoch Wray' is, in its nature and unconscious tendency, Epic; a whole world lies shadowed in it. What we might call an inarticulate, half-audible Epic! The main figure is a blind aged man; himself a ruin and encircled with the ruin of a whole Era. Sad and great does that image of a universal Dissolution hover visible as a poetic background. Good old Enoch! He could *do* so much; was so wise, so valiant. No Ilion had he destroyed; yet somewhat he had built up: where the Mill stands noisy by its cataract, making corn into bread for men, it was Enoch that reared it, and made the rude rocks to send it water; where the mountain Torrent now boils in vain, and is mere passing music to the traveler, it was Enoch's cunning that spanned it with that strong Arch, grim, time-defying. Where Enoch's hand or mind has been, Disorder has become Order; chaos has receded some little handbreadth, had to give up some new handbreadth of his ancient realm.

"Rudiments of an Epic, we say; and of the true Epic of our Time, — were the genius but arrived that could

[1] Carlyle, *Essays*, Vol. III, p. 161 (New York, Scribner).

sing it! Not 'Arms and the Man'; 'Tools and the Man,' that were now our Epic. What indeed are tools, from the Hammer and Plummet of Enoch Wray to this Pen we now write with, but Arms, wherewith to do battle against Unreason without or within, and smite in pieces not miserable fellow men, but the Arch-Enemy that makes us all miserable; henceforth the only legitimate battle!"

Since the "genius that could sing it" has not yet arrived, it is, unfortunately, not possible to study this "Epic of our Time" as much in detail as would be desirable for teachers of science. It is, however, possible to gain some insight into the reason why "Good old Enoch could *do* so much," before a "poetic background of universal Dissolution" and "encircled with the ruin of a whole Era." Is not his being "so wise, so valiant" that "where his hand or mind has been, Disorder has become Order" due in large measure to the fact that the method of thinking which he used when he made "the rude rocks send it water" was the only method that has ever proved effective when man wishes to control Nature and be able to predict the results of her processes? Did he sit still and lose himself in contemplation of "celestial" rocks and "immutable" water? Did he retire to his inner consciousness and just think Platonic thought until convinced of the "truth" of Bradley's

famous phrase "Nothing real can move"? Not he. There was a human need to be satisfied by grinding corn; he realized the need and longed to serve humanity by helping it to satisfy its hunger. So he studied the situation, formed a plan of action that seemed "expedient" under the circumstances, and then put his plan to the test of experience.

37. **The Parents of Physics.** — As has been stated, the conclusion that seems warranted from the preceding discussion is that Germanic industry was the father of modern physics. On the other hand, the father of the ancient science was a very different sort of being. For while Germanic industry is coöperative, democratic, and not afraid of work, the parent of ancient science was exclusive, aristocratic, and unwilling to soil his hands in work. As a result of their ancestry, modern physics is coöperative, democratic, and industrious, while ancient physics is exclusive, aristocratic, and lazy.

But though the classic and the modern physics have different fathers, they have the same mother. The Greeks recognized wonder as the mother of the sciences. In like manner, the moderns, as Dewey puts it, consider that "wonder is not only the originator, but it is the continuer of science. Wonder is the emotional outgoing of the mind toward this universe. It is the sole spring which can take a man beyond his subjective states, and

put him in that active relation to the world which is the sole condition of getting at its meaning. But it is no less true that wonder is the cause of all growth, of all increase in knowledge. Wonder as the outgoing activity of the mind, necessarily requires a surrender of all purely subjective and selfish interests, and the devotion of one's self to the object wholly for the sake of the latter." [1]

Thus ancient physics is related to modern physics because of the fact that both were mothered by that deep-seated human emotion of wonder. If her first marriage to that exclusive and aristocratic laziness of the ancients resulted in offspring who could not "surrender all purely subjective interests," but preferred thinking Platonic thought to working at the world's work, her second marriage to the coöperative and democratic industry of the Germanic races must have more than consoled her for her former misfortune; for modern physics is a son of whom any mother might well be proud.

38. **The Renaissance.** — No objection will be raised against this analysis of the history of industry, since all recognize its origin and its present importance. Many will, however, demur at the conclusion that modern physics is the son of democratic Germanic industry and

[1] Dewey, *Psychology*, p. 303 (New York, Harper, 1897).

not of aristocratic Platonic thought. Every history of physics and every history of philosophy treats the subject in chronological order, first describing the Greeks and their works and then passing on to modern times, as though there were no discontinuity, no break in the development. According to the story, Greek science was "preserved" by the Arabians through the "dark ages" and brought back into Europe during the Crusades and the Renaissance. Was not the period from 1200 to 1400 A.D. called Renaissance because its chief function was the re-discovery of the works of the ancients? And when these "preserved" works, which are "absolute" and "immutable" and which therefore contain the quintessence of all wisdom, were finally uncorked and freely imbibed in Europe, the moderns got so full of the ancient spirit that they have devoted themselves ever since to an effort to reproduce more of it.

39. **Archimedes.** — All this may be so as far as art and literature and the "humanities" are concerned, but nothing can be less true than this as far as physical science goes. The fact that Archimedes discovered the law of the lever and the principle of equilibrium of floating bodies is the mainstay of the idea that modern physics is a direct descendent of the physics of Aristotle. But both of these principles are *static*, while modern physics is *dynamic*. He solved the lever problem by

means of an artistic sense of symmetry — the equal weights at equal distances from the fulcrum are in equilibrium because then the whole system is symmetrical with respect to the axis; under these conditions *we can see no reason* why it should turn one way rather than the other; therefore it *must* remain at rest. Archimedes also gives rules for finding the centers of gravity of numerous things — not real bodies, however, but *geometrical figures*, triangles, squares, spheres, cylinders, and the like.

In the case of the floating bodies he comes nearer to the modern method of procedure. In this case, however, his problem was a *commercial* one, namely, to find out if the silver smith had cheated the king. In this case he actually tried an experiment, -- that of taking a bath, — but history fails to record whether he ever repeated the experiment or not. He is said to have weighed the crown to the discomfiture of the silversmith, but this is almost the only case on record of *measurements* having been made by a Greek philosopher; and, as has been remarked, this was done in the interests of industry.

We do find Ptolemy at Alexandria making measurements of the angles of incidence and refraction of light passing from air to water. But he was unable to do anything with his results when he had them. The "immutable idea" that was needed was not "innate"

in him: he had failed to notice "celestial" refraction in his "previous existence." It remained for Snell (1621), of Germanic tribe, to find the "form" into which the measurements of Ptolemy might be fitted; and he did it by a method of trial and error, or adaptation, approximation, and experiment.

The more one studies the methods used by ancient physics, the greater appears to be the disparity between them and those of modern physics. The physics of Aristotle was studied assiduously in the universities during the entire Renaissance and down to Galileo's time (1200–1550), yet with the exception of those pages devoted to Roger Bacon's protest against Aristotelian methods, the histories of physics have nothing but blank pages descriptive of this era. And when Galileo appeared on the scene, his first dramatic act was to refute forever Aristotle's dogmas about falling bodies by dropping a cannon ball and a bomb from the top of the leaning tower of Pisa. From that day the influence of Aristotle has steadily declined; but that it is not yet all gone is shown by the appearance in recent books of such phrases as "light *is* a wave motion in a medium that is *assumed*."

40. **Galileo and Guttenberg.** — As a reward for his impudence in daring to be the founder of a new science, Galileo led a hard life. Though part of a university,

he was not a party to its scholasticism. So he remained ever poor and struggling, was finally imprisoned, and died a natural death only because he deluded the officers of the church. Yet to-day he alone, of all his colleagues on the faculty at Padua, is remembered and honored. He is the morning star that heralded the new day on which the Germanic method of solving problems was destined to be applied to abstract thinking.

Looking back a century and a half from Galileo, we see Guttenberg, struggling to solve the problem of finding an expedient means of satisfying the human need for books. He, too, was poor and oppressed by debt, but he escaped the persecution of the Inquisition because his work was " practical " and did not seem to endanger the " absolute and infallible " ideas of Aristotle and the church. Yet was not his work, too, fundamental for the future of science, not because he made the diffusion of knowledge possible, but because he helped to establish the method of thinking that was needed before science could grow?

41. **Scientific Industry**. -- Was the work of Guttenberg the less valuable for scientific progress because his aim was the more practical? Is not the method of work at least as characteristic, if not more so, than is the purpose or aim? Agriculture is now fast becoming a " science " because it is employing the methods of science

instead of following the traditions of the past, although its purpose still remains the eminently "practical" one of supplying us with food. All the modern industries, in fact, are coming to deserve the title of science, although their aims still remain unchanged. It is, perhaps, needless to add that the present factory system of manufacture reduces the workmen to machines. Such unfortunates are engaged in neither industry nor science, as here conceived.

There are, of course, differences in the degree of refinement to which the method is carried in the cases of industry and science, and the purposes and aims of the two also differ in degree. But if industry quits when an "expedient" rule of thumb for the needs of the immediate situation has been found, while science continues until the need for a more general rule or law is discovered, is not this a difference in degree rather than one in kind? Bouasse says: "In the classification of forms, the practical value of a postulate is of little importance; or rather its value has no significance. It is a matter of drawing the implied consequences; to reason well is all that is demanded of the creator of a form."[1]

42. **The Method of Science.** — If industry meets human physical and mental needs by physical means

[1] Bouasse, *De la Méthode dans les Sciences*, p. 102 (Paris, Alcan, 1909).

only, while science forms theories and laws to satisfy the intellectual feelings of wonder, is not this again a difference of degree rather than of kind, since both are engaged in manipulating material things and creating forms to satisfy human needs? May we not, then, define the method of science in its broadest sense, as that method which furnishes the most expedient solutions of the problems defined by human needs? If this conclusion is accepted, the pedigree of modern physics is settled: Germanic Industry is its father, and Wonder is its mother. A further definition of this pedigree will be attempted in the next chapter.

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CHAPTER VI

The Method of Physics

43. **Method is Characteristic.** — In the last chapter, the fact that modern physics did not begin to develop until the value of the methods which it uses had won recognition among large bodies of men was interpreted to mean that modern physics is the child of industry. This interpretation seems necessary, if we agree to classify physics by its method rather than by its aim or purpose. Current ideas of modern science revolt at this determination of the pedigree of physics, because we at present have, consciously or unconsciously, come to classify the sciences by their aims rather than by their methods. The "pure" scientist is prone to regard industry and "applied" science after the manner of the Greeks; namely, as unfit occupations for a gentleman and a scholar. According to the academic creed, research which has no immediate practical application is the "academic ideal" of pure science, while the "mighty dollar" — the manifest goal of industry and applied science — is but a degraded "ideal of the market place."

It is to be hoped, however, that modern science will

welcome this interpretation of the facts with the same openmindedness with which it has recently welcomed the ion, the electron, and the relativity postulate. The story begun in the last chapter is not yet finished. "The child is father of the man," says the old adage; and, however paradoxical this may at first sight appear, it contains a deep truth. In this chapter, the attempt is made to justify the classification of physics by its method; and in the next we shall endeavor to show how physics, the child of industry in the sixteenth century, has become father of the man who, in the twentieth century, has come to be the mainstay and comfort of his aged parent.

44. **Scientific Training not Transferable.** — As has been pointed out,[1] the more or less conscious aim of physics teaching has been to train students to solve all their daily problems by the method of science. That this aim has not yet been achieved is now very generally recognized; if for no other reason, then simply because men of science themselves, though expert in the use of the method in the field of science, fail to use it in solving problems in economics, banking, law, and other "unscientific" fields of activity. The "mental discipline" acquired by training in physics, while it may lead to skill in solving the specific problems in physics, does not

[1] *Ante*, pp. 46 *sq*.

result in a general ability to solve problems in economics or politics in a scientific manner.

There are two main reasons why the training in science has not resulted in a general ability to think scientifically. One of these is the vagueness of our ideas as to the nature of the method of science; and the other is our ignorance until recently of the conditions under which general ability may be developed by specific training. The following discussion of the methods of science is intended, then, not only to justify the classification of physics by its method, but also to assist teachers in forming more definite ideas concerning the nature of the method of science. The question of the development of general ability by specific training is reserved for Chapter VIII.

45. **Definitions of the Method of Science.** — The attempts to define the method of science have been numerous indeed. Beginning with Bacon's *Novum Organum* and Descartes' *Méthode*, and continuing on down through Locke, Kant, Whewell, Mill, Lotze, to the recent works of Dewey, Poincaré, Mach, Duhem, and others, we have an unbroken series of profound works whose study, while most profitable, is a rather hopeless task for any physics teacher, loaded, as he is sure to be, with the endless details of his daily routine, and eager to keep pace with the rapid progress of his science.

Yet, notwithstanding the vast literature on the subject, there are numerous brief formulæ which have been worked out for the guidance of teachers and which are intended to make it possible for the teacher to teach in such a way that "habits of scientific thinking" are formed by students. One of these brief statements has already been quoted on page 47. For purposes of discussion another such statement from the preface of a recent text (1902) is here reproduced: —

"This new method of acquiring knowledge, which may be called the scientific method, has been often discussed, and there is substantial agreement as to the steps which it involves. They are: (1) the acquisition of individual facts, either by general observation or by the method of artificial observation known as experimentation; (2) generalization, the statement of a general relation which seems to exist between these individual facts; (3) deduction, the making of individual inferences based upon the generalization of the second step; and (4) experimentation, to test the accuracy of these inferences. A method which starts in the middle of the process, by stating the generalization and requiring the pupil to make the deductions only, may give a good training in deductive reasoning — in algebra and geometry — but it cannot teach physics nor give a training in the methods of physics. A method which

makes the generalizations and deductions and calls upon the pupil to verify these deductions by experiment likewise gives training in but one step of the process. The present textbook is a result of the attempt of the writer to apply this scientific method in all its steps to the teaching of physics."

At first sight this statement may seem to warrant the "substantial agreement" which its author claims for it. But when we turn to the pages of the text, we find the subject introduced after this manner: —

"**Physics.** — Physics is the science which treats of the changes that take place in the physical universe.

"**The Physical Universe.** — The physical universe is that part of the universe which is, so far as we know, made up of the two fundamental existences, Matter and Energy.

"**Matter.** — No complete definition of matter is possible. We may learn of the properties of material bodies, but the essential nature of matter is entirely unknown to us. The name is generally understood to mean the indestructible substance of all bodies which are appreciable by our senses.

"**Energy.** — The essential nature of energy is likewise unknown. We can measure its quantity, but we know nothing of its descriptive qualities. It may be provisionally defined as the capacity for doing work.

"**Work.** — The term *work*, as used in physics, may be defined as the producing of such changes in the relative positions or relative motions of material bodies as would require an effort on our part to produce."

The subject of wave motion and sound is thus introduced in this same book: —

"**Scope of the Subject.** — The form of energy transference known as wave motion is best studied in its relations to the phenomena of sound and light. Sound and light differ from other branches of Physics in that they involve both a physical and a physiological side. The physical side of the subject of sound is principally concerned with wave motions in elastic bodies. The physiological side is concerned with the sensations produced in the hearing organ by means of these wave motions.

"**First Law of Sound.** — The fundamental proposition in the study of sound is that all sounding bodies are in a state of vibration. These vibrations may be observed in a number of characteristic sounding bodies by means of the following experiments."

Many other passages of like character are found in the book, showing an utter failure on the part of the author to follow the formula of method which he himself has set up. And if he could not follow it himself, how can we expect others to do so? Hence, the first conclu-

sion to be drawn concerning this formula, which claims to be descriptive of the scientific method, is that it is fairly useless to the teacher.

46. **The Real Method.** — The reason for its uselessness is not hard to find if we attempt to apply it to a concrete case. Did Galileo follow it when he proved that bodies of different masses fall with the same acceleration? Many will answer this question in the affirmative, since Galileo certainly did, on the basis of his general observations on falling bodies, form the hypothesis that they fall with the same acceleration, and then proceed to verify the hypothesis. In this formal sense, he may be said to have followed the formula.

But what was it that led Galileo to undertake the investigation? Thousands upon thousands of others had observed falling bodies as well as Galileo. Why was it reserved for him to make the discovery? Was it not because he had read or heard of Aristotle's dogmas on this subject and had been led to wonder whether they could really be in accord with the facts? Thus scientific thinking does not begin with a mere collection of facts; it starts when some man begins to wonder what the facts really are and what they really mean; *i.e.* when some discrepancy is felt between the observed facts and their accepted interpretation.

And is not this ability to sense discrepancies in a situa-

tion — to feel that there is somehow a gap that needs bridging or a contradiction that needs adjustment — one of the chief factors that distinguishes the man of genius from other mortals? If Galileo had been unable to sense the discrepancy and to formulate the problem, he would never have attempted its solution. In like manner, unless Newton had felt that there was something wanting in his knowledge about gravity, — did its action extend to the moon or not? — he could never have solved the problem and established his theory of universal gravitation. Surely, then, this sensing of gaps, this feeling of discrepancies, is a fundamental part of scientific thinking. No scientist ever goes about gathering data unless he thinks they will be useful to him in accomplishing something he really wants to do.

It is this desire, this longing to find out on his part, that furnishes the motive that keeps him at work. Yet the steps in the scientific method as just outlined make no mention of this spring of motive from which all thinking flows. And is it reasonable to imagine that children will become scientific thinkers if we simply put them through the motions called for by the steps in the formula, unless we also induce in them motives in some way similar to those which impel real scientists doing real investigation? When Galileo first beheld the satellites of Jupiter through his telescope, he is said to have fallen on his

knees and fervently thanked God for having revealed to him such unsuspected wonders. And was not Archimedes so overcome with enthusiasm over the discovery of his principle that he completely forgot the proprieties of the occasion and ran about in charming dishabille, shouting "Eureka!" Is there any teacher to-day anywhere who ever observed any boy or girl become enthused with any such emotions as these after performing any one of the "forty experiments from the following list"? "If any, speak; for him have I offended!"

47. **Logic Follows Intuition.** — This, then, is the first reason why the formula given above for scientific thinking is useless. It fails to take account of the emotional element. Therefore, it cannot direct teachers in the paths of imparting knowledge, since "knowledge is impossible without feeling and will."[1] Because it thus fails to recognize the functions of the emotions, it is but a form of Platonic thought. It describes the logical steps which a mature mind can see might have been used in obtaining the result after the result has been obtained by more unconscious and tentative methods. No one ever follows such a cut-and-dried form of thinking when he is solving a real problem. A physician trying to diagnose a case is constantly making hypotheses, deductions, and verifications; he is selecting, dissociating, and

[1] Dewey, *Psychology*, p. 18 (New York, Harper, 1897).

associating ideas even while he is asking questions about symptoms, taking the pulse, watching the respiration, and so on. After he has solved the problem, he may organize it in his mind under the heads of the formula given, but this is only *after* he has reached the conclusion by less formal methods.

Such formulæ for the method of science have their place in treatises on logic, where the effort is made to devise a " form " into which thinking processes may be made to fit. But in actual life thinking is too subtle and flighty an operation to permit its reduction to any such simple forms. They are the useful tools and categories of the logician, rather than safe rules for a teacher to follow. We should never forget that " Demonstrations are constructed by logic, but inventions are made through intuition. To know how to criticise is good; but to know how to create is better. Logic teaches us that on such or such a path we are sure to meet no obstacles; but it does not tell us which path it is that leads to the goal. In order to find this out, we must see the goal from a distance, and the ability that enables us to do this is intuition. Without this, the geometer would be like a writer whose attention was riveted on the grammar, but who had no ideas."[1]

" The philosophy that investigates nature is philoso-

[1] Poincaré, *Science et Méthode*, p. 137 (Paris, Alcan, 1909).

phy as science; for this reason it is distinct from that dangerous and ever fruitless thing: philosophy as logic. . . . To appeal to pure logic for an interpretation of the world, — to logic and not to intuition, — and to fail to raise experience to the position of giver of laws, simply means willfully to bind truth in chains. . . . Hence, the new period of philosophy investigating nature began with a general insurrection against Aristotle. For this Greek not only analyzed the formal laws of thought, thus rendering their use more certain, and for which he deserves the gratitude of all future races, but he also undertook to solve by means of logic all problems that were not yet investigated, and even those that were not amenable to investigation. On this account science was impossible; for the silent assumption of logic is that man is the measure of all things, when in reality — as a purely logical being — he is not even a measure of himself. . . . In the entire system of Aristotle, logic, instead of being the servant, sits as queen upon the throne."[1]

It is, of course, essential that the teacher of science should know logic, but he must be wary of applying his mature logic too abruptly in his teaching. Intuition is the forerunner of logic in the method of science; and "the conscious setting forth of the method logically adapted for reaching an end is possible only after the

[1] Chamberlain, *Die Grundlagen des Neunzehnten Jahrhunderts*, p. 899.

result has been reached by more unconscious and tentative methods. Ability to divide a subject, to define its elements, and to group them into classes according to general principles, represents logical capacity at its best, reached after thorough training. But it is absurd to suppose that a mind, which needs such training because it cannot perform these operations, can begin where the expert mind stops. *The logical from the standpoint of subject matter represents the goal, the last term of training, not the point of departure.* In truth, the mind at every stage of development has its own logic."[1]

The elements of the method of physics to which we have thus far endeavored to draw attention are, then: 1. The emotion of wonder which comes first, senses the problem, and is, therefore, the "originator and continuer of science"; 2. The importance of intuition in "seeing the goal from afar"; and 3. The position of logic as servant rather than queen, — as a bodyguard that follows after and helps intuition in removing obstacles on the way to the goal. These factors are here emphasized because, although they are the fundamentally important ones for teachers, they seem to have escaped general notice in the numerous and vast literature of this subject. This is one of the results of Platonic thought.

[1] Dewey, *How We Think*, pp. 113, 62.

48. The Concrete and the Abstract. — Besides these three factors, there are several others which, if not grasped by the teacher, will impair his success in training in scientific thinking. The first of these is the relation between the concrete and the abstract. As has been already pointed out, " the origin of thinking is some perplexity, confusion, or doubt. Thinking is not a case of spontaneous combustion; it does not occur just on ' general principles,' There is something specific which occasions and evokes it. General appeals to a child (or to a grown-up) to think, irrespective of the existence in *his own experience* of some difficulty that troubles him and disturbs his equilibrium, is as futile as advice to lift himself by his boot straps."[1]

" Thinking must end as well as begin in the domain of concrete observations, if it is to be complete thinking."[2] The usefulness of this sentence depends on the meaning attached to the word " concrete." Most people seem to think that anything which is " made of matter " — a sidewalk, a house, a mathematical model, or a piece of physical apparatus — is concrete to everybody because it is a material thing. According to this classification, the concrete is marked off from the abstract by a fixed boundary which is the same for everybody, namely, that between matter and non-matter. According to this

[1] Dewey, *Ibid.*, p. 12. [2] *Ibid.*, p. 96.

conception, it is immaterial what material thing is used to introduce a topic in physics; an unfamiliar piece of what Poincaré calls "bizarre apparatus" will do just as well as some familiar thing from the child's own experiences; since both are made of matter and hence "concrete."

Yet the concrete cannot be so definitely marked off from the abstract. "To one who is thoroughly at home in physics and chemistry, the notions of *atom* and *molecule* are fairly concrete. They are constantly used without involving any labor of thought in apprehending what they mean. The terms convey meaning so directly that no effort at translating is needed. Concrete denotes a meaning definitely marked off from other meanings, so that it is readily apprehended by itself. Thus the concrete is purely relative to the intellectual progress of an individual; what is abstract at one period of growth is concrete at another. There is, nevertheless, a general line of cleavage which, deciding upon the whole what things fall within the limits of familiar acquaintance and what without, marks off the concrete from the abstract in a more permanent way. *These limits are fixed mainly by the demands of practical life.* Things such as sticks and stones, meat and potatoes, houses and trees, are such constant features of the environment of which we have to take account in order to live, that their impor-

tant meanings are soon learned, and indissolubly associated with objects."

"By contrast, the abstract is the theoretical, or that not intimately associated with practical concerns. The abstract thinker deliberately abstracts from application in life; that is, he leaves practical uses out of account. What remains when connections with use and application are excluded? Evidently only what has to do with knowing considered as an end in itself. Many notions of science are abstract, not only because they cannot be understood without a long apprenticeship in the science, but also because the whole content of their meaning has been framed for the sole purpose of facilitating further knowledge, inquiry, and speculation. When thinking is used as a means to some end, good, or value beyond itself, it is concrete; when it is employed simply as a means to more thinking, it is abstract."[1]

The foregoing definitions of the concrete and the abstract are not only the clearest, but also the most useful ones available for the teacher. According to them, a piece of physical apparatus, like that used to introduce the subject of Pascal's law on page 86, is not concrete to the pupils simply because it "occupies space and affects the senses," *i.e.* because it is made of matter. On the other hand, the water taps in the school or the

[1] Dewey, *How We Think*, pp. 136–138.

home, together with the fact that the water rushes out more violently in the cellar than on the third floor, are concrete to the pupils because familiar and filled with significance for their daily lives. Such concrete material furnishes a suitable starting point for the discussion of Pascal's law, and supplies a ready basis for the definition of a problem. When a state of uncertainty as to what the water will do, or as to how the piping is arranged to produce the observed effects has been induced, thinking begins. It is then easy to lead on to an hypothesis and thence to experiments and measurements.

49. **Wide Association Necessary.** — There is another fundamental reason why it is important to introduce topics with the concrete as just defined. The water system is already associated in the pupil's mind with a wide range of experiences. When he has achieved the law on the basis of such concrete material, he finds no difficulty in applying the law to practical cases. The law becomes associated automatically with the experiences because of its mode of development in his mind. Every physics teacher wonders why pupils find it so difficult to apply the principles of physics to daily life. The difficulty is due in large measure to the failure to begin the discussions with material that is concrete to the pupil. By beginning with apparatus or principles that are really abstract to him, we fail to make use of the wide

range of associations always grouped about a truly concrete idea; and if the discussion is thus abstract at the beginning, no amount of exhortation on the part of the teacher will make it possible for the pupil to bring it back to earth again.

50. The Place of Applications. — One other point on this topic needs to be noted. "Thinking must end as well as begin in the domain of concrete observations, if it is to be complete thinking."[1] All textbooks have problems and exercises after the demonstration of a principle, thus recognizing the need of ending in the "domain of concrete observations." But if these problems are of the type quoted on page 89, they are not concrete as here defined. They are not taken from real experience, and the ideas which they contain — dyne, energy, acceleration, *t*th second, etc. — are to the pupils abstract. Such problems are merely problems that are made up to be problems and do not present concrete situations in which there is some discrepancy to be cleared up or some gap to be filled.

Many books refer to machines and daily experiences at the end of the "demonstration" of a principle, citing them as "applications." This practice is good, provided the demonstration also began with familiar concrete material. "The true purpose of exercises that apply

[1] Dewey, *How We Think*, p. 96.

rules and principles is not so much to drive or drill them in as to give adequate insight into an idea or principle. To treat application as a separate final step is disastrous. . . . When the general meaning is regarded as complete in itself, application is treated as an external, non-intellectual use to which, for practical purposes alone, it is advisable to put the meaning. The principle is one self-contained thing; the use is another and independent thing. When this divorce occurs, principles become fossilized and rigid; they lose their inherent vitality, their self-impelling power. . . . The teacher needs, indeed, to supply conditions favorable to use and exercise; but something is wrong when artificial tasks have arbitrarily to be invented in order to secure application for principles." [1]

51. The Method of Physics. — While a physicist is laboring over a real scientific research in physics, he finds it difficult, if not impossible, to guide his thinking according to any logical formula. But when he has solved his problem, he describes the process by telling how he first sensed an inconsistency, or a discrepancy, or a gap in a system of ideas which were concrete to him; how he then, by search for related ideas and facts, or by both, succeeded in defining the problem sharply; how he formed a plan of action or theory to serve as a tentative solution

[1] Dewey, *How We Think*, p. 212.

of the problem; and, finally, how he deduced the consequences of the theory and tested them by experiment. This is excellent logical form for telling about his investigation after it is done. But it is clear enough that he never laid out his investigation in advance in any such sharply defined steps. During the process of the solution of the problem, he was constantly associating, dissociating, and ordering ideas, making inductions, deductions, and verifications; and, in short, thinking as we all think by processes that are too complex to be analyzed.

So it is with the children. We cannot teach them to think; they already do this. We can, however, help them to learn to think *well*. But this result is not likely to follow a series of mental gymnastics which are ordered according to a logical formula that was constructed on the basis of post mortem examinations of scientific work. The teacher is much more likely to succeed if he creates such a situation that the pupils will sense inconsistencies and begin to wonder what the trouble is. He may then criticise their attempts at defining the problem, may follow out with them the consequences of their guesses at its solution, and encourage them to seek in the laboratory the further information that may be needed, and that cannot be obtained except in the laboratory. In short, the teacher will be more likely to succeed in training the pupils in good thinking if he becomes like the kodak

fiend — "he presses the button and the children do the rest."

52. The Truth of Physical Laws. — One final point which is of the greatest importance to teachers remains to be noted. It is the question of the truth of the laws of physics. At present many pupils leave the physics classes with the impression that the physicists have settled every possible problem in physics because they have discovered "laws," which "govern" nature and are eternally fixed and immutable, — veritable Platonic ideas.

Nothing can be less true than this. For in the first place, laws express relations between variable quantities, and the "form" of these relations is determined by fitting measurements to a theory. But all measurements are approximate, and never exact. Therefore, they never do fit exactly, or absolutely into the "form." More exact measurements sometimes bring observations more closely into accord, so that they more nearly satisfy the law or form selected; and sometimes they lead to the discovery of new factors and make necessary a change in the law. But in any case, they are never absolutely correct, and so the laws remain true to their Germanic characteristic of approximation. Every teacher admits this freely, but many fail to impress it on the pupils.

On close examination, the laws of physics are found to be even less immutable than is implied in the fact that they are close approximations. They are but human interpretations of natural phenomena, and there is nothing to prevent new interpretations from being made at any time, provided only that they square with all the known facts. Such new interpretations are constantly being made and are one of the sources of continual growth. In some cases, as, for example, when the phenomena of light were interpreted in terms of electricity, we are able to check up the new interpretation and prove it to be an improvement on the old one, in that it resumes more phenomena under fewer ideas.

But in other cases, as in the non-Euclidean geometry and the relativity postulate, we have not yet been able to prove by experiment that these interpretations are truer or more exact than those now in use. In such cases, we choose not on the basis of truth, but on the basis of convenience. As Poincaré puts it in regard to the adoption of the Euclidean geometry:[1] "Our mind has adopted the geometry most advantageous to the species, or, in other words, most convenient. Geometry is not true, it is advantageous." Again:[2] "This affirmation: 'the earth turns round' has no meaning, since it can be verified by no experiment; since such an experiment not only

[1] Poincaré, *Science and Hypothesis*, p. 65. [2] *Ibid.*, p. 85.

could not be either realized or dreamed by the boldest Jules Verne, but cannot be conceived of without contradiction; or rather these two propositions: 'the earth turns round' and 'it is more convenient to suppose the earth turns round' have the same meaning; there is nothing more in one than in the other."

It is difficult for us, who have come to accept the statement 'the earth turns round' as absolutely true, to realize that this is but the most convenient and simplest interpretation yet found of all the facts of experience. The evidence in favor of this interpretation is so overwhelming, that we feel a distinct repugnance against admitting it to be only "expedient." This feeling of repugnance is even more marked when it is suggested that Euclidean geometry is not a body of necessary truth imposed on us from on high, but only the simplest and most convenient method of interpretation of space relations. Yet no one should refuse to accept this latter conclusion until he has studied carefully Poincaré's essays [1] on the subject. His conclusion is particularly cogent when he says: "Why be astonished, then, at the resistance which we make to any attempt to dissociate things that have long been associated? It is this resistance itself which we call the evidence of geometrical

[1] Especially Part II on Space in *Science and Hypothesis*, and Book II, Chapter I, on the Relativity of Space in *Science et Méthode*.

truth; this evidence is nothing else than the repugnance which we feel in breaking up very old habits with which we have always been satisfied."[1]

If we accept the conclusion that the laws of science are true only in so far as they are found to be the most advantageous interpretations of phenomena, the difference between the speculations of Plato and Aristotle and the laws of modern physics becomes very striking. The "ideas" of the former were immutable, absolute, and imposed on men from on high; their doctrines were dogmatic, and thinking was a discreet function of the human mind and the only one that could lead to "oneness with the absolute." By contrast, the interpretations of modern physics are tentative, relative, and wrought by human industry; its laws have been found to be expedient guides in forecasting the future, and thinking is only one of several coördinate factors in the activities of a living, feeling humanity.

Greek thought has been useful to modern physics in furnishing many ideas that were the inconsistent elements in situations in which problems became defined, as in the case of Galileo mentioned on page 131. The absolute, the immutable, the pure thinker, the proud know-it-all, are Greek; the relative, the ever changing, the industrious doer, the humble seeker for larger truth, are Ger-

[1] *Science et Méthode*, p. 108.

manic. Well may modern physics say with Æneas: "Timeo Danaos, dona ferentes."

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CHAPTER VII

The Biography of Physics

53. What are the Characteristics of Physics? — In Chapter V the hypothesis was advanced that modern physics is the child of industry, and the justification for this hypothesis was found in the fact that the positive method of thinking, which is the stronghold of physics, had to win recognition among large masses of men, by proving that it was the only method capable of giving expedient solutions of industrial and commercial problems, before physics could begin. Having proved its worth in solving these concrete problems, the time was ripe for its application to more abstract problems.

It was also pointed out that the motives that lead men to study these more abstract problems are very different from those which impel men in industry and commerce; still it seemed more advantageous to classify physics with Germanic industry, thus regarding their common method as the more important factor, than to continue to think of its motive as all important and to classify it with Platonic thought. As has been stated, this classification will seem to many to be degrading to physics.

Those who feel this way about it should remember that several of the sons of industry have made the best Presidents this country has ever had; and there is no sufficient reason why the child of wonder and industry should not have possessed other traits of character that were as important in making him great as was the method and the spirit inherited from his parents. We shall seek to discover such traits in the following study of the development of the child.

54. **Galileo's Work.** — Galileo is justly regarded as the founder of modern physics. He is usually mentioned in the elementary textbooks because of his experiment on the Tower of Pisa and his discovery of the relation between distance and time for freely falling bodies. In some of the more advanced texts, the modern ideas of force and inertia are ascribed to him, while others give credit for these to Newton. Now if these are the sole claims of Galileo to honor, the children of to-day are little interested in him or his work. When the teacher has carefully repeated the experiment of rolling the balls down the inclined plane, and has demonstrated that the distances are proportional to the squares of the time intervals, are not the children almost sure to react with a feeling of "Well, what of it?" Why should they care whether the distances are proportional to the squares or to the cubes of the time intervals? What can they do

with the information? Does it solve any problem of their own making or remove inconsistencies in some real situation that is concrete to them? Is there nothing more than these meager facts to be secured from a study of Galileo's work?

The reply of the current academic physics is: "Yes, from his experiments with the inclined plane, he showed what acceleration is, developed the scientific idea of inertia, and gave us the modern notion of force as the cause of acceleration." Very well, but, though the physicist may know how to appreciate the value of this information, will the great majority of the pupils cease to ask: "Well, what of it? What more can we do with these ideas than with the commonplace ideas of inertia, velocity, and force?"

It seems strange that the schoolbooks are satisfied to present only this much of Galileo's work, and to assume tacitly one other important point which Galileo thought it necessary to consider theoretically and to prove experimentally. As is well known, he tried the experiment of rolling balls down the inclined plane because the freely falling ball moved too quickly to be observed with accuracy by the means at his disposal. So after he had determined the relations for the plane, he asked himself whether they were analogous to those for free fall. This problem resolves itself at once into the more specific one:

Is the velocity acquired by sliding down a plane the same as that acquired by falling freely through the height of the plane?

In the reply to this question, Galileo reasoned somewhat as follows:[1] "If we should assume that a body falling down the length of an inclined plane in some way or other attained a greater velocity than a body that fell through its height, we should only have to let the body pass with the acquired velocity to another inclined or vertical plane to make it rise to a greater vertical height than it had fallen from. And if the velocity attained on the inclined plane were less, we should only have to reverse the process to obtain the same result. In both cases a heavy body could, by an appropriate arrangement of inclined planes, be forced continually upwards solely by its own weight — a state of things which wholly contradicts our instinctive knowledge of the nature of heavy bodies."

Having reached this conclusion by reasoning, Galileo tried his well-known experiment with the large pendulum, driving nails at various points in the wall so as to catch the string of the pendulum and make the bob rise on one side along an arc of shorter radius than that of the arc along which it descended. In this way he proved that

[1] Mach, *Science of Mechanics*, Engl. Tr. by McCormack, p. 135 (Chicago, Open Court, 1893).

his intuition, that bodies did not of themselves rise to higher levels, was correct. The experiment is seldom mentioned in elementary texts; yet it is one of the fundamental experiments in physics.

55. **The Causal Principle.** — It is clear enough that the intuition that guided Galileo in his reasonings on this problem was that of the impossibility of perpetual motion. Mach says:[1] "In the arguments by which Galileo is led to his discoveries, an important rôle is played by the principle that a body rises because of the velocity acquired in falling to exactly the same height from which it has fallen. This principle, which appears frequently and with perfect clearness in the writings of Galileo, is but another form of the principle of the impossibility of perpetual motion."

Mach then shows that the fundamental and tacit assumption of all science is the causal principle, which is often expressed by the phrase "every action has a cause." In the ancient science, it was final and absolute causes that were sought. Here the causal principle appears in the form of that of sufficient reason; as in the case of Archimedes, mentioned on page 119, the equal-arm lever was in equilibrium because it was symmetrical about the axis, and we can see no reason why it turns one way

[1] Mach, *Die Geschichte und Wurzel des Satzes von der Erhaltung der Kraft*, 2d ed., p. 7 (Leipzig, Barth, 1909).

rather than the other. But in modern physics this causal principle appears in a different form. It manifests itself as a deep-lying intuition that every phenomenon is related to some other phenomenon. As Mach puts it, "The causal principle is characterized with sufficient clearness when we say that it assumes an interdependence of phenomena among one another."[1]

Modern physics, then, does not seek final causes, but recognizes that phenomena are related in such a way that when a change is wrought in one group, corresponding changes occur in some other group. It is the form of the relation between two groups of simultaneously changing phenomena that modern physics seeks to determine; and this is just exactly what Galileo did. He found the form of the function that expressed the relation between distance and time for a ball rolling down the inclined plane, and that which expressed the relation between velocity acquired and vertical distance of fall both for bodies falling freely and for bodies falling under constraint. Galileo is the first physicist in whose work this modern view of the causal principle appears with perfect clearness.

56. Perpetual Motion. — But this is not all. The recognition of the relatedness of phenomena appears in another intuition which is really the guiding star of

[1] Mach, *Die Geschichte und Würzel des Satzes von der Erhaltung der Kraft*, 2d ed., p. 35 (Leipzig, Barth, 1909).

modern physics. If one change never takes place in one object without a related change taking place in some other object or objects, intuition at once senses the impossibility of perpetual motion. This is, of course, no quantitative proof; it is but a qualitative intuition, which "sees the goal from afar." It is perfectly clear that Galileo both had this intuition and proved it quantitatively for the special case of bodies falling freely or down inclined planes. It is this, more than anything else, which entitles Galileo to his position as founder of dynamics. His discovery of the fact that forces determine acceleration, while a great contribution to physics, as distinguished from ancient science, is not as important as is his tacit assumption of the relatedness of phenomena and the consequent intuition of the impossibility of perpetual motion.

One other important point in Galileo's work is his treatment of the motion of projectiles. In this case his assumption is that each of two simultaneous motions produces the same effect as it would produce if taking place alone, *i.e.* that the two motions are really independent, so that the resultant motion may be found by algebraically adding them.

57. **Newton's Work.** — In Newton the causal principle appears in full brilliancy in the modern form. For Aristotle the stone fell because it, acting alone, sought its

natural place. But for Newton stone and earth are related bodies which determine for each other mutual accelerations. His extension of the idea of mutual relationship to the sun and planets was a magnificent extension of the relativity idea, and brought a vast range of mechanical phenomena from the realm of intuition into that of quantitative proof and logic. What more explicit statements of mutual interdependence could be made than "every particle in the universe attracts every other particle," and "action and reaction are equal and opposite"?

The recognition of the interdependence of phenomena seems to be the soul of Newton's laws of motion. The first may be regarded as a statement of the fact that a wholly isolated or independent body suffers no change of motion. The third tells us that whenever a change of motion does occur, *at least two* bodies are mutually involved; and the second and third together exemplify the spirit of modern physics by giving the form which expresses the relations involved in the mutual action of two bodies, namely, the momenta are equal ($m_1 v_1 = m_2 v_2$).

The greatness of Newton's work does not, however, consist solely in the fact that he perceived the interdependence of phenomena. Because he was able to pick out those characteristics of phenomena that could be easily measured and to devise expedient methods

of measuring them, he was able to bring his perception or intuition of relatedness into a quantitative form in which it was capable of verification. As has been noted, Galileo determined by measurements the form which expresses the relation between the two variables, distance and time, for bodies rolling down an inclined plane, and also perceived that forces were related to accelerations. Newton brought this perception of Galileo's into the realm of positive and quantitative fact by introducing an arbitrary constant, mass, and proving by numerous experiments the validity of the form force = mass × acceleration.

This form, as Newton uses it, is a definition of the most expedient method of measuring force. In it mass becomes, as Poincaré shows,[1] a "coefficient which it is convenient to introduce into calculations." This relation makes force, as thus defined, the center of the Newtonian system, and leads at once to the doctrine of central forces and to momentum as the measure of action and reaction. These, then, are the tools, fashioned by Newton, with which physics has worked for more than two hundred years. Their expediency is proven beyond question by the long series of triumphs which have been achieved by their use, especially in the field of celestial mechanics, where there is no friction.

[1] Poincaré, *Science and Hypothesis*, p. 76.

But if Newton possessed the intuition of the relativity of mechanical processes, he gives no direct evidence of having felt the impossibility of perpetual motion. The ideas of work and energy are difficult to discover in his *Principia*. It is true, that, in the scholium to the third law, he does mention the equality of the products of the weights and the vertical distances on the two sides of a lever as one of the conditions determinative of equilibrium. But he makes no further use of this idea. For the problems he had in hand his definitions and axioms were adequate and expedient.

It is difficult to conceive that Newton did not perceive that perpetual motion is impossible, especially since both Galileo and Huyghens had already made such fruitful use of the intuition. It seems far more probable that he did perceive it, but did not mention the fact, because, with the science of heat still in the intuitive stage, he could not treat it in the same rigorous way in which he treated the other mechanical relations, action and reaction, for instance. It may be that he was so much influenced by Descartes and by the fact that momentum is conserved in impact that he deliberately dismissed work as an unfruitful idea. Whatever the reason may be, it is clear that the idea of work plays a negligible rôle in Newton's own system as he left it.

58. Newton's Successors. — But if Newton himself

failed to make use of the idea of work, it soon came to the front in the work of his successors. The extension of Newton's principles to terrestrial mechanics soon led to the discovery of general principles of mechanics, like D'Alembert's principle and that of least action. But all of these are *work* principles. In this connection Lagrange's proof (1788) of the principle of virtual velocities is instructive. He conceives all the forces that are acting on a body to be replaced by sets of pulleys about which one continuous cord is passed. On the end of the cord a weight is hung. The number of sheaves in each set of pulleys is so chosen that the set really replaces the force. It is then clear that equilibrium results when the weight cannot descend. In other words, equilibrium results because heavy bodies do not of themselves ascend. The fundamental assumption here is again the impossibility of perpetual motion. Lagrange and others have tried to find other proofs of this principle, in which this assumption is not made, but without avail.[1]

In the century that passed between the publication of Newton's *Principia* (1686) and Lagrange's *Mécanique Analytique* (1788) the genius of Europe was employed in working out the consequences of Newton's definitions and axioms. Lagrange's work may be regarded as the

[1] For a full discussion of this point see Mach, *Science of Mechanics*, p. 65 *sq*.

completion of the edifice whose foundations were laid by Newton. His ideas were found adequate to serve as a basis for celestial and analytical mechanics; taken as mathematical forms, they have proved fruitful in the extreme. But the physical content of these forms has always been a matter of controversy and discussion.[1] A comparison of the methods used to introduce Newton's laws of motion in various texts shows that teachers are not agreed at present as to just what they mean. The more recent texts have finally come down to introducing them with a statement like this: "Over two hundred years ago Sir Isaac Newton published three laws of motion which were generalizations from experimental data and facts of common experience. The first law is:" etc.

59. **Introduction to Mechanics.** — It is, nevertheless, perfectly clear that the student will not see at once that they are generalizations of common experiences. He will not even see that a body in motion continues in motion unless stopped by some force; much less is the measurement of force by acceleration an immediate percept from common experience. To him the book on the table weighs just as many pounds when it is at rest as it does when it is in motion; and does he not have

[1] For example, Pearson, *Grammar of Science*, Chapter VIII, 2d ed. (London, Black, 1900).

to row hard in a boat to keep it moving uniformly? Why, then, is force measured by acceleration? These and many other difficulties of like nature cluster about the teaching of these laws *at the beginning* of a course in physics. The trouble seems to lie in the fact that it requires considerable power of abstraction to grasp the idea that these laws ignore our sensations of force and give us no information about what mass and force are, but only define the most expedient and rigorous way of measuring them. These laws are fundamental to a logical and rigorous interpretation of mechanical relations; but there is a yawning chasm between the intuitive and anthropomorphic interpretation which children bring to the study of physics and the analytical mechanics of Newton and Lagrange.

There can be little doubt that from the point of view of logic and rigor, the Newtonian method of approach to the study of mechanics is an excellent one. It is also evident that every prospective physicist ought to master the ideas of this method of treating mechanics. But we are here considering the use of physics as a means of general education, and from this point of view it may well be doubted whether the mere statement that these laws are verified by all our common experiences will suffice to convert the anthropomorphic conceptions of youth into the clear-cut mathematical conceptions of

analytical mechanics. Even supplementing the statement by citing some experiences does not always help to clear the matter up, as the following example, intended to clarify the matter for the pupils, will show.

In one of the latest of the college texts of physics, the statement of Newton's first law is introduced, as it should be, by reference to common experiences. Among those mentioned is this: "A locomotive, in pulling a train with uniform velocity along a level track, exerts force sufficient to overcome friction, air pressure, etc., but no more." Then follows the statement of the first law. After this we read: "This law is embodied in the equation $F = Ma$. If a be zero, there is no force." With such a presentation, how can the student fail to wonder which statement is correct? If the locomotive exerts a force when it is pulling the train with uniform speed, when $a = 0$, by what magic has the introduction of the equation suddenly proved that there is no force? There is no explanation of the anomaly in the text, and so the student is left in a muddle, torn with conflicting emotions between his intuitive perception of the correctness of the first statement and his mathematical sense that the equation by some hocus pocus proves the second. This muddle is liable never to be cleared up, excepting in the cases of a few of those who are hardy enough to go on into advanced physics in spite of it. Yet both

statements are correct. The former is true when force is defined in the common-sense, engineer's way; and the latter is rigorously true when defined by the Newtonian definition. It is doubtless a fine thing for physics to carry the student over from one definition to the other, since this marks an advance in logic and in abstraction. But when it is done as it is in the case just cited, the students may well exclaim, "Oh, George! but this is so sudden!"

60. **The Advent of the Steam Engine.** — But to return to the biography of physics: as has been noted, there was little done in physics during the century following the publication of the *Principia*. We find a number of men experimenting with static electricity, but the majority of those who were mathematically inclined were studying Newton and perfecting the celestial and analytical mechanics to which he made such brilliant contributions.

Towards the end of the century, physics proper began to revive. A new era may be said to begin with the invention of the steam engine by James Watt (1789). It was this invention and the studies that Watt made in heat that turned the attention of the physicists in this direction. For the purpose of this discussion it is not necessary to follow the development of thermodynamics in detail through the work of Rumford and others down

to Sadi Carnot. It is with the investigations of Carnot, J. R. Mayer, and Joule that we are particularly concerned.

Carnot's brief treatise (*Reflections sur la puissance motrice du feu*, Paris, 1824) marks the beginning of this reduction of a second great domain of physics from the realms of intuition and perception to those of logic and law. The gist of Carnot's work lies in his demonstration that for a given amount of work the quantity of heat that flows from the higher temperature t to the lower temperature t_1 does not depend on the nature of the working substance, but only on the range of temperature. He reaches this conclusion because, if it is not true, a combination of bodies could be imagined which would enable us to produce work continually from nothing. Thus here again, the intuition that perpetual motion is impossible pointed the way to the goal. The fact that Carnot's demonstration is faulty does not alter this argument, since his principle is correct, as was shown later by Kelvin by a different method.[1]

61. **The Conservation of Energy.** — The importance of Carnot's work for the present day physics no one denies. His cycle, his principle, and his ideas of reversible and irreversible processes started a long line of

[1] For a fuller discussion see Magie, *The Second Law of Thermodynamics* (New York, Harper, 1899).

most fruitful investigations. When complemented by the investigations of Mayer, Joule, and Helmholtz, they not only brought heat under the sway of measurement, but also showed that there was a constant ratio between the conventional work unit of mechanics and that of quantity of heat; namely, 1 British Thermal Unit = 778 foot pounds.

The electrical unit, the watt-second, soon yielded to the same treatment, and was found to bear a constant ratio to the unit of heat quantity. Whenever the ratio between two units is constant, we know that the units are different units for measuring the same thing. This *same thing*, which may be measured in foot pounds, in British Thermal Units, or in watt-seconds, is called *energy*. Therefore, because of this constancy of the ratios between various pairs of these units, the doctrine of the conservation of energy became a necessity.

It is important to note in this connection that the principle of the conservation of energy does not assert that the sum total of all the energy in the universe is constant. In this form it would sound well, but be practically useless. What it does tell us is that there are constant relations between the *units* by which we *measure* mechanical work, quantity of heat, and electrical work, *i.e.* between the foot pound, the British Thermal Unit, and the watt-second (or the erg, the

gram calorie, and watt-second). Because of these constant ratios, it is possible to reduce all units of measurement to those of mechanics. In other words, the doctrine of energy supplies us with a common terminology and a common system of units for all branches of physics. It thus unifies the definitions of physics, since a definition is of little use in physics unless it tells how the quantity defined is measured.

62. **Energy in Physics and in Industry.** — At present we may say that this guiding intuition of physics, this sense of the impossibility of perpetual motion, this recognition of the relatedness of physical phenomena, has become pretty well incarnated in the realms of law and logic. If at first it was but a vague and half-conscious intuition, it has now become a very real and well-established fact. And it is interesting to note that the name given to that *constant something* which is measured either in foot pounds, in B. T. U., or in watt-seconds is the same as that given to that *conscious something* in terms of which the accounts of the world are settled — energy. The man of commerce may think that the world's accounts are settled by money; but the student of real physics, — of physics as it is, as distinguished from physics of the schools, — he knows that energy is the final basis of industrial values.

It can hardly be by chance that physics and the world

of commerce and industry both use the same idea as the idea that unifies their standards of value. But since it is so, why not make the vast range and variety of experiences, which every one has accumulated about the ideas of energy, the starting points for the problems of physics? Why is it considered necessary to make a detour through the elements of analytical and celestial mechanics before starting in on *real* physics? Any one who can measure in pounds and feet, and who can read a thermometer, a voltmeter, and an ammeter, can begin to make measurements in energy. He can even measure the pull of the engine on the uniformly moving train in pounds, though its value be zero in dynes! He can in this way become interested in the physical world about him, can begin to organize his vast range of associated experiences about the fundamental ideas of physics, and by and by he may even be able to sail off into space and find joy in applying the analytical and celestial mechanics to determining the perturbations of minor planets or the orbit of the tenth satellite of Jupiter.

63. **Work Precedes Logic.** — It is important to note in closing that the foregoing argument in favor of beginning the study of physics with considerations of energy relations makes no mention of the question whether the Newtonian or the Energetic school of physics is preferable. This problem is one which is

still in process of solution. That may turn out to be quite a different story. Fortunately, it has little bearing on the problem of using physics for purposes of general education. Beginning with ideas of work is advocated because work measured in foot pounds is a concrete idea which is easily grasped by most young people and which is also already associated in their minds with a very wide range of experiences. It is easy to lead from studies of the efficiencies of simple machines on to the Newtonian mechanics if the teacher wishes to do this. Since this is at present the best-established form, it will probably be safe to continue to do this for the present.

The logical is, nevertheless, always the goal toward which the instruction is aimed; but the imposition of the logical on the student at the very start is fatal to the success of the whole undertaking. He must be led from things that are to him concrete on to the abstract. In this he follows in a vague sort of a way the general development of physics. Since the motive of this development has been the feeling for relatedness and the intuition of the impossibility of perpetual motion, these elements should be prominent at the beginning as well as all through. The purpose is to bring these intuitions from the sphere of the vague and indefinite into the realm of the concrete and the logical.

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CHAPTER VIII

The Discipline of Physics

64. The Doctrine of Formal Discipline. — On pages 34 and 36 two passages are quoted, one from an old textbook of natural philosophy (1846), and the other from a recent textbook of physics (1902). These passages illustrate the change that took place in the methods of treating physics during the interval between the publication of the first and that of the second book. This change from one form of treatment to the other was brought about by two main causes; one was the rapid development of university physics, and its gradual soaking down into the schools from above; and the other was the prevailing educational doctrine, which reached its final statement in the Report of the Committee of Ten. In the preceding three chapters an attempt has been made to define the real nature of the first of these causes; it remains, therefore, to consider the meaning of the second.

The doctrine of formal discipline is very old. It was implied in the educational practices of the Greeks and the Romans. It was not, however, until the age

of scholasticism that it appeared as a consciously formulated principle of education. "All one needed was training in logic, in intellectual gymnastics, and from this source of knowledge, the inner consciousness, could be spun all good and worthy things."[1] Its close kinship with Platonic thought is worthy of note. Physics was taught in medieval universities under the influence of this doctrine. It consisted in endless hair-splitting disputations concerning the meanings of Aristotle's speculations. Observation and experiment, as well as emotion and feeling, were totally overlooked. The students were to learn physics, not by studying the physical phenomena about them, but by doing something else; namely, by juggling with words and meaningless statements called by them definitions.

The doctrine came to be still more explicitly defined about the middle of the eighteenth century, when the exclusive study of the classics in schools began to be attacked by a public hungering for a real education. It was then that the schoolmen flew to the defense of the classics with a more explicit statement of the doctrine. The essence of this doctrine is thus given by Monroe[2]: "The mind as a bundle of faculties was to be developed

[1] Bennett, *Formal Discipline*, p. 9 (Teachers College, New York, 1907).

[2] Monroe, *Text-book in the History of Education*, pp. 505 *sq.* (Macmillan, 1905). Quoted by Heck, *Mental Discipline*, p. 13 (2d ed., New York, Lane, 1911).

by exercising these various powers upon appropriate tasks whose value consisted in the difficulties they offered. These faculties were considered to have no necessary connection with one another, hence these disciplines were separate and distinct things; though some faculties were higher than others. The highest was the reasoning power to be developed by appropriate discipline in mathematics, logical disputations, and the languages; but the faculty upon which all the others depended, and upon the successful development of which depended the success of the education, was the memory. Discipline of the memory, then, took precedence above all other exercises. The best training for the memory was afforded by the mastery of material which had no inherent interest for the child."

This defense of education by classics alone on the ground of their peculiar fitness to give "mental discipline" has persisted with strange pertinacity down to the present time. When the last great reaction against confining education to a study of the classics alone began, shortly after the Civil War, about 1870, the position taken by the schoolmen of the eighteenth century was appealed to again with great effect.

65. The Work in Modern Languages. — The effect of thus defending the classics on grounds of mental discipline, instead of on grounds of inherent literary worth,

has been disastrous both to the classics themselves and to the newer subjects that were striving to displace them. Thus when the demand came from the people for living instead of dead languages, these new aspirants for academic honors were required to attack the classics in their fortification of mental discipline. French and German found the fortress well-nigh impregnable, and were at last compelled to erect fortifications of their own. They did this by copying the methods of the classics, reducing the study of the modern languages to grammatical analysis, parsing, and learning of paradigms. That was the way the classics secured "mental discipline," hence the moderns must do likewise.

Even English fell a victim to the craze, and editions of Shakespeare and of other "English classics" began to appear in which the text occupied often less than half the book and the "explanatory notes" and guides to parsing took up the rest. The inevitable result followed. Young people no longer read Shakespeare for the pleasure and the culture that comes from absorbing the world's great literary masterpieces. The writing of "English themes" is often one of the hardships of life; — all because English set off on a wild-goose chase after mental discipline as used by the classics for self-defense in this their last memorable struggle. English teachers have recently waked up to the truth of Dewey's

remark, " There is a great difference between having to say something, and having something to say."

66. Formal Discipline in Science. — Not only the languages, but the sciences as well, and even manual training, fought their way into the schools on the ground that they furnished " mental discipline " and so contributed to " culture." For the Platonic notion that thinking is a separate and distinct function of life, and, therefore, that intellectual training is the sole end of education, was everywhere accepted without question. Science and manual training might never have been able to break into the academic hierarchy of mental discipline if they had sought entrance on their own legitimate grounds of practical utility and the training of the whole boy to usefulness in life. And when they did gain admission, they at once went to work to make good and prove that they could give mental discipline of the good old orthodox kind, with all its methods of mortification of the will for the glory of the intellect.

67. Peculiarities of the Doctrine. — There are several curious features of the doctrine of mental discipline which are as hard to understand now as is the doctrine of infant damnation. One is the claim that it is impossible to learn to speak English well without having studied Latin. In other words, the child learns to do one thing by doing something else. By the same token

he learns to understand his present surroundings by studying an ancient history consisting mainly of a list of emperors with the dates of their wars. When physics came under the sway of this idea, it soon became changed in the way shown in the quotations on pages 34–37; that is, if you want the pupils to learn physics, you should teach them pure mathematics.

Another of the curious features of the doctrine is its insistence that certain specified kinds of subject matter are inherently endowed with the power of giving mental discipline to those who merely rub up against them for a given length of time. These preëminently disciplinary subjects are those mentioned on page 12, and proclaimed by the Committee of Ten as being "proper for secondary schools." The belief in the necessary truth of this idea is still prominent among the public at large. Many a poor girl at present sacrifices her opportunities for a real education in domestic science or horticulture for a schooling in Latin and algebra, under the impression that she is thereby winning admission to an intellectual caste in which alone she will be happy. On close analysis the evidence for the necessary truth of this idea is found to be the same as that for the necessary truth of the ideas of geometry, as mentioned on page 146; namely, the repugnance which the mind feels to changing old and deep-seated prejudices.

The college entrance requirements are founded on this idea. It makes no difference whether a student is really able to do the work required of him in college; if he has not "had" foreign languages, mathematics, and English as taught in the schools under college supervision, he is not a fit subject for college. The effect is perfectly normal. The student is "immune" to these subjects in college; very much as he is immune to the measles, or any other disease of childhood, after he has once "had" them.

68. Formal Discipline in Physics. — The effect of these ideas on physics is so clear that he who runs may read. Physics is usually given in the third or fourth years of the high school so that the pupil may have "had" algebra and geometry before coming to the physics. Physics must be taught by teaching something else; namely, mathematics. The physics teachers then wonder why the pupils do so poorly in "physics" and complain bitterly that the students cannot do "physics" because they know no mathematics. In reality the thing is perfectly normal; they have "had" mathematics and so are immune.

Under these conditions the mathematics teachers have attempted to assist the physics teachers by correlating physics with mathematics. In one recent text in which the authors claim to have done this, there are

found a few equations from physics, like $s = \frac{1}{2} at^2$, which are introduced with some remark about their being equations often met with in physics, and then solved like any other equations in algebra. The fallacy of this procedure is perfectly clear; the train of reasoning is incomplete, since every complete train of thought must begin and end in the *concrete*.

In the case of physics, this doctrine is well named that of " formal " discipline, since it has led physics to attempt to give discipline by forcing a study of " form " with little content. Newton started the habit by presenting his *Principia* in geometrical form and order *à la* Euclid, because he was too sensitive to take pleasure in friendly scraps with his colleagues. It is perfectly clear that the " forms " which Newton sets up had content to him; and it is equally clear that they do not have content to high school pupils, until they have passed through a long series of well-planned experiences and experiments which begin in situations which are concrete to them and gradually lead up to the establishment of the desired form. Hence physics, in its efforts to give " discipline " in accordance with the old doctrine of formal discipline, has floated off into a world of forms, totally oblivious to Lincoln's statement that a man's legs should be long enough to reach to the ground. It may be said to have given lots of " discipline," if the word is used

in the sense of punishment; for the harder the job and the greater the pupil's aversion to it, the greater was its value for discipline. Its religion has been: "the heavier the cross, the brighter the crown."

69. **Psychology to the Rescue.** — But a new day is dawning for the school children. The science of psychology is coming to their rescue, by proving that the human mind is not made up of separate faculties of which reason and memory are the chiefs. Thinking is no longer an isolated function, set off by itself in a celestial region of frigid bliss. It is part of a process in which the whole mind is engaged, including the volitions, emotions, imaginations, tastes, aversions, and the rest. The mind no longer has a separate thought-tight compartment called memory, another called reason, and another called imagination, and so on. Instead, each mind, acting as a whole, has memories, reasonings, and imaginations. In the words of Thorndike:[1] "The mental sciences should at once rid themselves of the conception of the mind as a sort of machine, different parts of which sense, perceive, discriminate, imagine, remember, conceive, associate, reason about, desire, choose, form habits, attend to. Such a conception was adapted to the uses of writers of books on general method and

[1] Thorndike, *Educational Psychology*, p. 187 (New York, Teachers College, 1910).

arguments for formal discipline and barren descriptive psychologies, but such a mind nowhere exists. There is no one power of sense discrimination to be delicate or coarse, no capacity for uniform accuracy in judging the physical stimuli of the outside world. There are only the connections between sense stimuli and our separate sensations and judgments thereof, some resulting in delicate judgments of difference, some resulting in coarse judgments. There is no one memory to hold in a uniformly tight or loose grip all the experiences of the past. There are only the particular connections between particular mental events and others, sometimes resulting in a great surety of revival, sometimes in little. And so on through the list. Good reasoning power is but a general name for a host of capacities and incapacities, the general average of which seems to the namer to be above the general average in other individuals."

70. **The Problem of Transfer of Training.** — This radical change of base has opened up a large field of investigation. If reasoning is no longer the isolated activity of a special faculty of the mind, but is the result of a very complex and varied interaction of many elements, it no longer follows that a mind trained to reason well in geometry will reason well in economics. The other elements that interact in the reasoning process may be very different in the one case from what they are in the

other. Therefore, it is by no means a self-evident fact, as the doctrine of formal discipline assumes it to be, that reasoning in geometry develops an abstract or generalized power of reasoning which will be of equal service in any other field. In fact, common experience shows this not to be so, since mathematicians are by no means the most acute and skillful reasoners on questions of finance, politics, business management, and the like. The absent-minded and impractical college professor has become a standing joke.

But if it is certain that training in reasoning in geometry does not necessarily result in developing general powers of reasoning, it is equally certain that many student of geometry do gain from that study something which strengthens their mental fiber and clarifies their mental operations. Hence the great problem for educational psychology is to find out under what conditions training in one kind of activity results in increased power of dealing with some other kind of activity. To be specific, if the greatest use of physics in education is to assist in developing among the pupils at large a scientific attitude of mind in dealing with all their problems, the physics teacher must understand the conditions under which the *specific training* given in the physics class results in *general ability* to deal scientifically with specific problems in other fields than that of physics.

This is an extremely complex and difficult problem. It involves a careful study not only of the relations between any given subject matter and the environment of the school, but also of the individual differences of the pupils, and "the respective shares which sex, age, 'race' or remote ancestry, 'family' or immediate ancestry, and the circumstances of life have in the causation of such differences. What we think and what we do about education is certainly influenced by our opinions about such matters. . . . For example, manual training is often introduced into the schools on the strength of somebody's confidence that skill in movement is intimately connected with efficiency in thinking. The American school system rests on a total disregard of hereditary mental differences between the classes and the masses; curricula are planned with some speculation concerning mental development as a guide." [1]

But as in physics, so in psychology, "effective description of the facts of individual differences and of their causation must be quantitative. The questions are questions of amount, or at least become such when carried beyond the first survey. 'Do boys and girls differ?' is itself a question of amount, which soon becomes, 'How much do boys and girls differ?' 'In what do they differ?' and can be answered only by comparing them

[1] Thorndike, *Educational Psychology*, p. 1 (New York, Teachers College, 1910).

quantitatively. . . . 'What is the value of Latin?' means to even the student most averse to quantitative thinking, 'What changes in human nature are caused by it?' But to prove the existence of any change, one must measure two conditions."[1]

Thorndike then goes on to explain the specific problems that arise when one undertakes to make quantitative measurements of individual differences, and gives numerous examples in which such quantitative data have been obtained. This science of psychology is, however, still in its infancy. It needs a Newton to give mathematical form to the definitions of this "spiritual mechanics." Thorndike concludes (p. 192): "Just what the original relations are, will in the progress of research be discovered. But present knowledge is insufficient to determine even the original relations."

71. Training is Specific. — Even though our present knowledge is not sufficient for this purpose, there are a number of working hypotheses, which have been advanced by the advocates of the new doctrine, and which have proved themselves to be both suggestive and fruitful to teachers. The rest of this chapter will be devoted to stating those hypotheses and ideas that seem to promise most for the teachers of physics; their problem being to find out how to give, by their instruction in

[1] Thorndike, *Educational Psychology*, p. 2 (New York, Teachers College, 1910).

physics, a training that shall be of the greatest possible value for purposes of general education.

The first point to be noted is that training in any subject is specific, not general. Much of the vagueness of the older doctrine lies in the fact that it assumes that training in general is possible. The Greeks and others have made the same mistake about thinking, assuming that thinking is some sort of a general activity whose laws and principles could be established in general. But thinking, like training, is always specific, *i.e.* connected with some particular situation and dependent upon the specific nature of the situation as a whole. In order to induce a student to think, it is necessary to place him in a definite situation which necessitates his thinking. In like manner discipline is best secured not by imposing artificial tasks or formal routines inherently distasteful to the pupil, but by creating a specific situation from which discipline results.

The fundamental education of man was secured from his relations with nature ages before schools were invented; yet nature never forces on men problems that are just made up to be problems, and that have no further significance. The problems of nature arise when some particular individual, impelled by motives and feelings of his own, undertakes to accomplish some specific thing in the perfectly definite situation in which he finds him-

self at the moment placed. The discipline that he gets in solving the problem comes from his own motivated efforts to master the difficulties which obstruct his path, but which are integral parts of the situation as a whole. Hence discipline and the training that results from it are not vague and general processes, but specific and definite results of the interactions of the specific elements of specific situations.

72. **Specific Discipline sometimes Transferable.** — But, notwithstanding the fact that each particular situation gives each particular individual a specific piece of discipline, which may be different for different individuals in apparently identical situations, the element of discipline derived by an individual from one situation may enable him more easily to master difficulties in apparently dissimilar situations. In other words, the discipline received by an individual in one situation may be "transferred" and become manifest in his reaction to quite different situations. The old doctrine of formal discipline assumed that this was universally true, — that the discipline secured from a study of mathematics, for example, would make any one a keen reasoner in any other field. The new theory states that this is true only in a limited way, and seeks to explain the limitations by assuming that discipline secured by an individual in one situation gives him increased control over some other

situation only when the two situations have elements in common, or "identical elements," as Thorndike calls them.

73. **Identical Elements.** — The new theory attempts to determine what are the identical or common elements in any two situations. But this is no easy task, because of the complexity of every situation. Thus an instructor in physics presents an experiment to his class. The common presence of the class in one room watching the experiment would, at first sight, lead one to suppose that the elements of experience derived by each pupil would be the same. But this is by no means necessarily the case, because of the individual differences of the pupils. For example, the common elements in an exhibition of a steam engine and the experiences of to-morrow will be very different for boys and for girls. So the common elements between an experience in physics and one in the world at large are not confined to identity of subject matter. They may be psychological, emotional, or ideal; it is therefore difficult to locate them with any degree of certainty.

Nevertheless, the theory of identical elements is suggestive of many fruitful ideas to any teacher who is seriously trying to teach his science in such a way as to make the training given of the widest possible use, *i.e.* to give to its discipline the largest amount of transferable

value. Some of these ideas are here presented in the hope that teachers may be willing to try experiments for the purpose of finding out what common elements are most efficient in securing transferable training; for it is clear that these elements will not be discovered by Platonic thought or by any other *a priori* method of attack. For purposes of presentation we shall consider some of the possible common elements: (1) in subject matter; (2) in method of treatment; and (3) in emotional reaction.

74. **Subject Matter.** — The number of possible elements of subject matter which physics has in common with other situations in life is very great. The phenomena of physics crowd upon every individual at every turn of his daily experiences. The home, the street, the school, are all filled to overflowing with them. The industries of the town and the country are rich mines of possible elements common to physics and the daily life. For example, if the topic is heat, there are cook stoves, furnaces, fireless cookers, refrigerators, houses, clothes, frost, dew, drying, sunshine, smelting, forging, casting, besides the problems connected with heat engines, gas manufacture, control of heating plants, heat equivalents of coal, matches, sparkers, fireworks, firearms, putting out fires, fire proofing, and the like. The teacher who begins his work in heat with topics of this sort, carefully selected with reference to the things most familiar in his

environment, will be almost sure to strike something that has for everybody common elements of subject matter.

Thus the first suggestion from the theory of common elements is that the teacher will be more likely to give a discipline that will be of value outside the physics classes, if he makes copious use, especially at the beginning of each topic, of the materials ready to hand in the immediate environment of the pupils. He is all the more justified in doing this (1) because, as was shown in Chapter V, physics is the son of industry; and (2) because, as was shown in Chapter VII, the idea which supplies the common denominator in terms of which the phenomena of physics are measured — that of energy — is the same idea that furnishes the common denominator for the settlement of the industrial and commercial accounts of the world.

75. **Common Elements of Method.** — The elements of method common to physics and the daily life are also numerous and far reaching. As Dewey[1] has shown, "there is no difference of kind between the methods of science and those of the plain man. The difference is the greater control in science of the statement of the problem, and of the selection and use of relevant ma-

[1] Dewey, *Studies in Logical Theory*, p. 9 (University of Chicago Press, 1903).

terial, both sensible and ideational. The two are related to each other just as the hit-or-miss, trial-and-error inventions of uncivilized man stand to the deliberately and consecutively persistent efforts of a modern inventor to produce a certain complicated device for doing a comprehensive piece of work. Neither the plain man nor the scientific inquirer is aware, as he engages in his reflective activity, of any transition from one sphere of existence to another. . . . Observation passes into development of hypothesis; deductive methods pass to use in description of the particular; inference passes into action with no sense of difficulty save those found in the particular task in question. The fundamental assumption is continuity in and of experience." [1]

But if the scientific method of solving problems does not differ in kind from that of the plain man, the two do differ in the degree of refinement to which the various phases of thinking are pushed. Herein lies one of the great opportunities for the physics teacher. He has the chance to help refine and sublimate the thinking of the plain man until it becomes scientific. And if the pupils begin their thinking about physics in the method to which they are accustomed, namely, that of the plain man, and are led on to more and more critical and impersonal

[1] Cf. also Minot, The Method of Science, *Science*, Vol. xxxiii, p. 119, Jan. 27, 1911.

habits of thought, does not this tend to preserve common elements of method? And the more these common elements are preserved, the greater is the transferable value of the teaching.

The methods of teaching now in use generally fail to do this, as shown in Chapter IV. When the student enters upon his study of physics, he strikes at the very beginning impossible definitions and mathematical statements of laws which are as intelligible to him as if they were written in Chinese characters. He discovers no elements common to physics and the rest of his experiences, and is immediately and irretrievably cut off from securing from his study of physics a discipline that shall be of any great value to him outside of the physics classes. Hence, those teachers who would give transferable training in physics should reason like plain men at the beginning. The upper limit to their reasoning is set only by their own abilities and those of their pupils.

76. Ideals of Method. — Besides the common elements, there is another factor which is of great importance in making a *method* transferable. After a very illuminating discussion of this topic, this factor is thus described by Bagley:[1] "What I carry over from my school work to my farm work is not a generalized *habit* of work, but a generalized *ideal* of work. This ideal furnishes a motive

[1] Bagley, *The Educative Process*, p. 212 (New York, Macmillan, 1910).

and this motive holds me to conscious persistent effort until the new habit has become effective, until the distracting influences no longer solicit passive attention. *If I had acquired a specific habit of work in one field without at the same time acquiring a general ideal of work, my acquisition of a specific habit in another field would probably not be materially benefited.*" Again, page 216: "This increased power must always take the form of an ideal that will function as a judgment and not of an unconscious predisposition that will function as habit. In other words, unless the ideal has been developed consciously, there can be no certainty that the power will be increased, no matter how intrinsically well the subject has been mastered."

In further definition of the point Bagley continues, p. 222: "An ideal is a type of condensed experience. It is the upshot of a multitude of reactions and adjustments, both individual and racial. As a condensed experience, it functions in the process of judgment. It serves as a conscious guide to conduct, especially in novel and critical relations. . . . The development of an ideal is both an emotional and an intellectual process, but *the emotional element is by far the more important.* Ideals that lack the emotional coloring are simply intellectual propositions and have little directive force upon conduct. . . . That the emotional element is dominant in the de-

velopment of ideals indicates that mere didactic instruction from the intellectual standpoint is not sufficient. The emotional spirit of the instruction is the factor that counts."

Since a scientific habit of mind, when developed in physics, is not transferable, while a conscious *ideal* of scientific method is transferable, it is important to note the distinction between a habit and an ideal. Among the ideals which physics may well foster are those of suspended judgment, of open-mindedness, of just weighing of evidence, of impartial observation, of impersonal judgment, of trying to get at all the facts. These ideals are the ones which a teacher who desires to give transferable training in physics will endeavor to develop consciously in his students. And can physics retain its hold on *general* education, if it is unable to do its share toward building up such *general* ideals as these?

77. **The Emotional Element.** — But Bagley has pointed out that in an ideal the emotional element is by far the most important. This emotional factor is the third of the categories under which we are seeking the elements common to physics and the rest of the world. In this field it is at once clear that physics and the world at large have all possible emotions in common. The feelings evoked by instruction in physics range all the way from exultant enthusiasm and self-forgetful devo-

tion, to melancholy despondency, anger, and despair. It is because of this wide range of possible emotions that another great opportunity is open to the teacher in selecting and emphasizing those emotions that are of the highest order and of the greatest value both to the individual and to society. It is in doing this that the teacher shows his most subtle art, since the work must be done unconsciously. A conscious exhortation to enjoy any given emotion ends disastrously. Feelings seem to be controlled by the situation as a whole.

78. **The Intellectual Feeling of Wonder.** — In Chapter V it has been pointed out that there is one feeling that is particularly characteristic of true science, namely, wonder, which is the "originator and continuer of science." If the teacher would cultivate this feeling in his pupils, he must know himself how it feels, and must be able to detect its presence in his pupils. He must, therefore, know some of its characteristics. This intellectual feeling of wonder is thus described by Dewey:[1] "Intellectual feeling, like all feeling, takes the form of an *interest in objects*. It is directed outward; it can find its satisfaction only in an outgoing activity of self. Intellectual feeling considered in this aspect is *wonder*. Wonder is the attitude which the emotional nature spontaneously assumes in front of a world of objects. The

[1] Dewey, *Psychology*, pp. 303 *sq*. (New York, Harpers, 1897).

feeling is utterly incomprehensible as a purely personal or selfish feeling. Wonder is the first and final expression of the individual as it finds a universe over against it. . . . Wonder is the simple recognition that objects have significance for us beyond the mere fact of their existence. A wide development of the feeling of wonder constitutes *disinterestedness*, the primary requisite for all investigation. . . . Wonder necessarily requires the devotion of one's self to the object wholly for the sake of the latter. . . . It is vitiated by the presence of any merely personal interest. When the activity occurs not for the sake of the object, but for the sake of satisfying the personal emotion of wonder, we have, not disinterestedness, but *curiosity*. Curiosity is an abnormal feeling. It is possible, however, for intellectual feelings to assume still more unhealthy forms. Such we have when knowledge is sought for the gratification of vanity, or for the sake of show or power. A more subtle form is that distinctively nineteenth-century disease, the love of culture, as such. . . . Culture of our mental powers is made an end in itself, and knowledge of the universe of objects is subordinated to this. . . . Here, as in all such cases, the attempt defeats itself. The only way to develop self is to make it become objective; the only way to accomplish this is to surrender the interests of the personal self. Self culture reverses the process, and

attempts to employ self-objectification or knowledge as a mere means to the satisfaction of these personal interests. The result is that the individual never truly gets outside of himself."

These being the chief characteristics of the emotion of wonder, it is easy for the teacher to know whether this feeling is at work among his pupils. If they lose themselves in the objective things they are doing and become absorbed in the study of the problem as an objective thing, the chances are very great that their emotions are of the right sort. This absorption in the objective study of problems is a well-recognized mark of genius, and a sign of the process of acquiring true knowledge. As Henderson puts it:[1] "In signaling out knowledge as the one cardinal virtue, one does not mean an idle erudition, a mass of abstract information, a technical equipment for the sake of the loaves and the fishes, an acquaintance with one or more foreign languages without anything special to say in any one of them; but one means that cosmic attitude of mind which leads one to seek to know things as they are, and to make one's thought and action partake of the same soundness and reality."

79. True Discipline Requires Motivation. — Perhaps the reader is wondering what all this has to do with discipline. The connection comes from the fact that this

[1] C. H. Henderson, *Children of Good Fortune*, p. 195.

emotion of wonder manifests itself in an interest in objects for the sake of the objects. "Because interests are things that have to be *worked out* in life and not merely indulged in themselves, there is plenty of room for difficulties and obstacles which have to be overcome, and whose overcoming forms 'will' and develops the flexible and firm fiber of character. To *realize* an interest means to *do* something, and in the doing resistance is met and must be faced. Only difficulties are now intrinsic; they are significant; their meaning is appreciated because they are felt in their relation to the impulse or habit to whose outworking they are relevant. Moreover, for this reason, there is motive to gird up one's self to meet and persistently to deal with the difficulties, instead of getting discouraged at once, or having to resort to extraneous motives of hope and fear — motives which, because external, do not train 'will' but only lead to dependence upon others. . . . There is only discipline when one can put one's powers economically, freely, and fully at work upon work that is intrinsically worth doing."[1]

For this reason, the problem of securing the best discipline is the problem of securing the best motivation for the work. But the best motivation comes from the emotion of wonder, which is the spontaneous feeling of the

[1] Dewey, *Interest as Related to Will*, p. 32 (University of Chicago Press, 1903).

self before a world of objects, and which manifests itself in an impersonal and unselfish effort to get at the real facts of the case.

This chapter contains the statement of what may be called the working hypotheses of the coming democratic education as they apply to physics. They are not finished laws and final truths; for such are found only in Platonic thought and its doctrine of formal discipline. What is most needed at present is intelligent experimentation to test the validity of these working hypotheses and to correct and amplify them as may be found expedient. The problem which they define is a relatively new one in education, and may be stated thus: to find what and how many of the elements that are common to physics and to life can be used to give a discipline which shall be most efficient in developing the characters of the majority of the pupils and which shall also have the greatest possible transferable value.

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PART III

HINTS AT PRACTICAL APPLICATIONS

CHAPTER IX

THE CONCRETE PROBLEM

80. Importance of Daily Experiences. — In the preceding chapter, emphasis has been laid on the idea that instruction should begin with discussions of experiences of the daily life and with practical applications of physics. The claim was made that this sort of an approach was much more likely to supply the kind of motivation that is needed if the study of physics is to give real discipline. This idea is entirely in harmony with the conclusion in Chapter V that physics is the son of industry, and with the findings of Chapter VI that the method of science begins with a problem defined by a human need, and with the facts presented in Chapter VII showing the present close relationship of physics and industry, due to their common practice of evaluation in terms of energy.

Notwithstanding this unanimity in pointing to daily experiences and industry as the best starting point for instruction, no one should conclude that the study of

physics should remain entirely in this domain of the practical. As has been noted on page 189, the upper limit of the teaching is placed only by the abilities of the teacher and the pupils. That a free use of industrial materials and practical applications *at the beginning* need not and should not make the study basely utilitarian has been pointed out also by Bagley as follows:[1] —

"It is much more probable that the emphasis of economic applications will make a much more forcible and much more general appeal, and thus serve more effectively to give point and vitality to the ideas of method and procedure and thus turn them into ideals. After all, the prime source of emotional factors is the fundamental needs of the individual, and the next most prolific source is humanity and its needs. When a high school pupil finds that a rigidly controlled method of procedure, coupled with a rigorous exclusion of irrelevant factors, including his own prejudice and bias, gains results that are of service to him and to the race, it is likely that he will have much more effective respect for the method and its rigorous qualities than he would gain if it were attempted to carry him through a series of experiences ending in the contemplation of a logical and coherent body of facts and principles."

"At every point, the advocate of applied science seems

[1] Bagley, *Educational Values*, pp. 207 *sq.* (New York, Macmillan, 1911).

to have the better of the argument, — so long as he limits his plea to the approach, and so long as he recognizes the immanence of the method and spirit of science, as compared with its facts and principles. He may well maintain that the method and spirit have no meaning, except as productive of facts and principles, and that if such facts and principles can be so chosen as to represent a maximum of utility without at the same time interfering with the fulfillment of the disciplinary functions, it is economy to make the choice on this basis."

81. Industrial Study of Science. — It will be noted that the point of view here presented as applied to physics is one of importance for industrial education as well. That many, if not all, of the attempts at industrial education have been decried by the formal disciplinarians as wholly utilitarian and, therefore, educationally useless, is due, first, to the fact that this is sometimes true; and second, to the fact that few realize that for young students a richer discipline can be given by a training that is founded on the industries, but flies higher, than by one that flies too high at the start. Even the eagle has to come to earth now and then for real nourishment. There is nothing inherently incompatible between industrial education and the discipline of pure science. In fact, from the point of view here presented, they are identical; and the clergyman, the doctor, and the lawyer

need this mental discipline founded on industry even more than do the toilers with their hands. It is one of the most basic factors of any genuine liberal culture.

For this reason the discovery of the methods of rendering this industrial study of science, or this scientific study of industry, if you prefer, an effective weapon of genuine educational discipline, is at least as important for the academically standardized schools and colleges of liberal culture as it is for the industrial schools. It is a conscious ideal of scientific procedure that is the goal, and "the future of our civilization depends upon the widening spread and deepening hold of the scientific habit of mind; and the problem of problems in our education is therefore to discover how to mature and make effective this scientific habit. Mankind so far has been ruled by things and by words, not by thought; for till the last few moments of history, humanity has not been in possession of the conditions of pure and effective thinking. Without ignoring in the least the consolation that has come to men from their literary education, I would even go so far as to say that only the gradual replacing of a literary by a scientific education can assure to man the progressive amelioration of his lot. Unless we master things, we shall continue to be mastered by them; the magic that words cast upon things may indeed disguise our subjection or render us less dissatisfied with it, but

after all science, not words, casts the only compelling spell upon things."[1]

82. The Administrative System. — In the light of the facts and working hypotheses presented in the preceding pages, it is clear that the general problem of the physics teacher is that of finding out how to make the work in physics contribute most effectively to the development among the pupils of transferable ideals of scientific method. It is equally clear that the methods that have been used to develop physics teaching into its present well-organized condition are utterly incapable of yielding the desired result. These methods have been described in Chapters I and III, and consist in the setting up of a syllabus of topics and experiments sanctioned by the "authority of official utterance," and enforced by college entrance examinations. The conscious purpose of it all is that the student may secure "a comprehensive and connected view of the most important facts and laws of elementary physics."[2]

This system of standardization of schools and courses has been very effective as far as solving the problems of school administration is concerned. By the unit system which has been developed any college can compute the

[1] Dewey, Science as Subject Matter and as Method, *Science*, Vol. 31, p. 127, Jan. 28, 1910.

[2] *Ante*, p. 61.

fitness of a boy to enter college with a probable error of perhaps twenty school minutes; and the Carnegie Foundation can determine the fitness of a college to have its venerable professors pensioned with a probable error of one semester-hour. All this is excellent, and an admirable thing for administrative convenience. By it the administration of the schools has been reduced to an exact science. It has brought order out of chaos, has developed a system of absolute units in terms of which all school phenomena may be measured, and has established a "credit system" which makes it possible for a student to get a degree without thinking for it. It has led to the belief, current in many quarters, that all educational problems are at bottom financial problems. On the other hand, it has tried to force uniformity of practice where such uniformity was impossible, thereby killing the thing for which alone administration exists.

83. **The Needs of the Masses.** — Excellent and important as this administrative progress of the schools has been, it has left the educational problem practically where it was when the high schools were founded. As has been noted (*ante*, p. 12), the high schools were established in response to a demand from the masses of the people for a general education suited to their needs. No one can read the daily papers to-day, not to mention the literature of education, without seeing clearly that the

masses of the people are making the same demands at the present time. And the reason for this is not hard to find, as has been pointed out by Thorndike (*ante*, p. 181), "The American public school system rests on a total disregard of hereditary mental differences between the classes and the masses." One curriculum, consisting of so many bundles of ready-made information, selected by a Platonic ideal of the immutable nature of children's minds, was made to do duty for everybody.

The one curriculum has now broken down to make way for the many; but still the many fail to reach the masses. The schooling they offer is not democratic, notwithstanding the fact that rich and poor mingle together on equal terms in the classes. And no wonder, for "the doctrine of democracy in education and the doctrine of formal discipline cannot well be harmonized."[1] An aristocracy may succeed in divorcing thinking from the other functions of life, but every member of a democracy must feel and act, as well as think.

84. Syllabi do not Solve the Problem. — Not only is the system of regulating physics courses by syllabi and externally applied examinations wholly incompatible with a democratic or industrial study of physics, but also the methods of presentation which that system has called into being cannot be reconciled with the working

[1] Heck, *Mental Discipline*, 2d ed., p. 125.

hypotheses of this newer education. As shown in Chapter IV, these methods seek to impose a system of ready-made information on the pupil by the adult method of text — discussion — application. In the laboratory work the results of this system are often distressing. Much of the work consists of careful measurements of known constants. The success of the work is too often judged by the agreement of the result with its absolute or predetermined value. Since the apparatus remains the same in each laboratory year after year, the results required soon become preserved in student circles. Under these conditions the ideals developed by the work are anything but those of scientific method.

From all this it appears that the contents of Chapters I–IV of this book, while essential for an understanding of the present problem, shed little light on the way to proceed in the solution of that problem. In fact they may be said to have rather a negative value in warning us how not to proceed if we would attain results of value to education. They describe the way in which the schools reached their present administrative efficiency; but education shall not live by administration alone.

85. **Experimentation Needed.** — But if the problem cannot be solved by the methods previously tried, how can it be done? This question seems hardly necessary after the discussions in Chapters V to VIII. Whenever

a human need has made itself felt and defined a problem, how has the problem been solved, if not by the method of science? The only reason why this method has not been tried sooner is that the training and discipline which we science teachers received did not relate to significant things and so has not proved itself to be transferable; therefore, few have thought of trying to apply the methods of their physics to the problems of education; and the few who have thought of it have been restrained until very recently by the excellent administrative system which has just been mentioned.

It is, however, perfectly clear that if progress is to be made in teaching physics for purposes of general democratic education, opportunity will have to be given for careful and well-directed experimentation. This means that all attempts at detailed uniformity of subject matter will have to be abandoned, and all detailed syllabi revoked. In physics the only kind of syllabus that will not do injury is the kind adopted by the North Central Association of Colleges and Secondary Schools; and this contains only eighty-one topics, these being, as mentioned on page 67, those to which no physics teachers offer any objection. This is enough to furnish the common core of different courses in physics without hampering the teacher in adapting the work to his particular community.

86. Problems Needing Experimental Solution. — Wherever such detailed and obstructive syllabi have ceased to intimidate teachers by their "authority of official utterance," experimentation may well begin. Such experimentation may well be directed at first toward settling two questions; namely, first, what materials in the industries and the daily life have enough elements in common with principles of physics to be available and useful in making the approach to those principles? In other words, what materials of common experience can be effectively used in defining problems that will not only be significant to the pupils, but will also lead somewhere in physics? And secondly, what things in physics are worthy of study? Is accelerated motion, for example, a topic from which the pupils gain enough transferable discipline to entitle it to the time required to make it clear? Or are there other topics which yield larger returns for the same time? Questions of this sort cannot be answered on *a priori* grounds. The fact that acceleration is a fundamental idea in Newtonian analytical and celestial mechanics is not in itself a warrant for including it in the course. If it can be shown to have enough elements in common with life outside of school to make it significant to the pupils, well and good; but if this is not the case, it will have to make way for more vital topics.

Before very much can be done in this line of experimentation, the number of topics treated in most of the textbooks will have to be lessened, and more significant material introduced. All of the texts extensively used at present have in the neighborhood of 575 numbered paragraphs, each containing, from the fact that it is numbered, one or more new ideas. Since the "unit" in physics is defined as 120 hours of class work, the teacher who uses one of these books has about twelve and a half minutes for each paragraph. In this time he must present his illustrative material, his demonstrations, his questions, his laboratory work, and his problems. This condition reduces well-nigh to zero the chances for needed repetition, informal discussion, and the bringing in of neighborhood materials by way of introduction. It is useless to urge the teacher to skip paragraphs, for the argument is usually so logically arranged that the omission of paragraphs renders the subject even more unintelligible.

87. **Summary of Conclusions.** — The teacher who has followed sympathetically the discussions in all the preceding chapters may now give a more specific meaning to the slogan of modern physics teaching, — bring the physics close to the daily lives of the pupils. If the discussions have not proved convincing, they must at least have shown that the content of this slogan is

by no means as simple as at first sight it appears to be. This content, as here interpreted in the light of the new theories of democratic education, may be summarized somewhat as follows: —

Physics is the son of industry and the spirit of wonder. From its father it has inherited its method of solving problems, — a method developed by Germanic races and quite distinct from that of Platonic thought. From its mother it has inherited that impersonal and unselfish disinterestedness which makes it open-minded and ever ready to accept the most expedient and general solution of a problem as the truth.

The most important individual characteristic of the child Physics is his interpretation of the causal principle as meaning that every natural phenomenon is related to some others; so that no one object ever moves or changes unless some other object or objects are simultaneously affected in some way. To physics every act produces its indelible effect on the cosmos, however slight that effect may be. Impelled by this deep-seated intuition of the universal relativity of phenomena, physics has spent its life endeavoring to give concrete expression to the intuition and to reduce it to the realms of quantitative, mathematical form and logic. It has done this by seeking the related factors in phenomena and by determining by measurement the mathematical form that most

nearly expresses the relationship. In this it has been eminently successful, for its comprehensive principle of the conservation of energy may be regarded as a quantitative and logical statement of the fact that no single physical quantity ever changes its value or varies, unless some related quantity changes its value or varies in a corresponding way.

In its long search for the related elements of phenomena, and for the constant forms that express that interdependence, physics has finally chosen as the most expedient forms for expressing the most general relationships among terrestrial phenomena those that express energy relations. In this he again shows his close kinship with industry; since energy is the factor in terms of which industrial and commercial relationships are ultimately determined.

Thus physics consists of two fundamental elements, namely, (1) that activity which, inspired by the spirit of wonder, takes from the industries their method of solving problems, perfects it, and applies it to the solution of the problems of finding the constant relations that exist among the varying elements of the flux of phenomena; and (2) the knowledge which results from this activity, and which is always valid within the limits set by the accuracy of the experimental data. Whenever physics is used for purposes of general education,

both of these elements must be prominent. At present the second and less important receives almost all of the attention of both teacher and pupil.

88. Bringing Physics close to the Daily Life. — When considering how to bring physics as thus defined close to the daily life of the pupil, we must first remember Dewey's remark that "education is not preparation for life, it is life." Hitherto physics teaching has generally been conducted as preparation for the career of a physicist. Even if we grant that the present methods are well devised to secure that end, the end itself is absurd. In 1910, there were 167,000 pupils studying physics in the secondary schools of this country. Each year the colleges graduate how many who are destined to become physicists? Ten or twenty? Then why start the rest of the 167,000 on the road toward physicsdom? the more so, since schooling is preparation for a future career, but education is life.

Those who wish to make physics, consisting of both its fundamental elements, a part of the education, — namely, a part of the life of the pupil, — must consider that life in two directions. In the first place, we must consider the life when he comes into the physics class; and, in the second place, we must consider his career after he leaves the physics class. We must then seek to adapt the work to the condition of the pupil when he enters,

and to conduct the work during his stay in such a way that he carries with him when he leaves the greatest possible quantity of knowledge and ideals that will be of real service to him later. The working hypotheses of the new education, as described in the preceding chapters, give many suggestions and fruitful hints as to how this may be done. The most important of these may be summarized as follows: —

In order to bring physics close to the past life of the pupil, it is necessary that he perceive no sudden discontinuity in his experiences with the physical world when he begins the work. This means that the phenomena discussed and the method of reasoning used at the start should be those of the "plain man." This close connection with the industrial basis may be gradually loosened as the work proceeds, but it is very essential to establish it and make it close at the beginning.

In order that physics remain an important factor in the after life of the pupil, it is necessary that the discipline and training received in the physics class be of the transferable kind. This makes it necessary: (1) that the pupil be inspired with the spirit of wonder. This is accomplished when the solution of the problems set appeals to him as being worth while, and he loses himself in the work of solving them. (2) The pupil must acquire a conscious ideal of the scientific method of

solving problems. This is not accomplished by didactic teaching of a logical setting forth of the supposed steps of the process. It may be accomplished by repeatedly showing the pupil that this method always gives the most expedient solution of the problems that are significant to him and whose solution he is seeking with a spirit of wonder.

89. **The Purpose of Physics Teaching.** — These summaries of the working hypotheses under which physics may hope to become part of a genuine democratic education define for us the aim of teaching physics for purposes of general education in the following way: —

I. The purpose of teaching physics is to assist the pupils in acquiring the benefits of physics to the fullest possible degree.

The benefits of physics are of two kinds: they consist in the acquisition of

1. Useful knowledge of physical phenomena.

2. Discipline in the methods of acquiring this useful knowledge.

Knowledge of physical phenomena is useful in proportion as it is definite and quantitative. Definite and quantitative knowledge of physical phenomena is essential to every one in controlling his environment, in predicting consequences, and in making judgments that shall have the greatest possible degree of validity.

Discipline in the methods of acquiring this useful knowledge results not only in skill in weighing evidence and in criticising and testing data, in open-mindedness or the ability of holding conclusions tentatively and of altering them whenever new evidence demands it, and in the ability of predicting consequences and of making judgments that shall have the greatest possible degree of validity; but also in self-forgetfulness, perseverance, self-respect, and resourcefulness in the face of difficulties.

II. Knowledge of physical phenomena and discipline in acquiring it may be either specific or general.

Specific knowledge of physical phenomena is that secured from the study of physics apart from its bearings on other activities of life. This specific knowledge becomes more general in proportion as it has elements in common with and is associated with facts and experiences in other fields of activity. It may be called general only when it is interwoven with the widest possible range of knowledge and experience.

In like manner, discipline in the methods of acquiring this knowledge is specific when received while acquiring specific knowledge. It may be acquired by repeated use of the method in solving specific problems in physics. It becomes more general as the specific knowledge becomes more general, and as a conscious ideal of the method is formed and made general. This conscious

ideal of method is acquired and made general in proportion as the problems solved by it appear to the individual as being worth while, and in proportion as he strives for their solution under the impulse of the spirit of wonder, which fosters in him true purposes and motives of his own.

III. A student acquires the benefits of physics to the fullest possible degree only when both his knowledge and his discipline in methods of acquiring it have become general.

90. **The Prejudices of Our Schooling.** — The concrete problem before the physics teachers is that of experimentally testing this statement of the purposes of physics teaching with the idea of finding out how far it can be put into practice and in what ways it can be improved. This is no easy task, since the first essential of a scientific test is that the one who makes it be free from bias and prejudice; and this means freeing the mind from traditions and habits of long standing. We have had it so everlastingly drummed into us that it is our function to teach only the "facts and principles of elementary *physics*," that it is very difficult to realize that this may be accomplished best by beginning with and making copious use of the facts and experiences of daily *life*. Besides, the method here called for enables the teacher to "cover" less ground, — fewer pages of the text, or a

lesser number of the aforementioned facts and principles.

But this freeing of the mind from the prejudices of our past schooling, while difficult, is not impossible. In several communities teachers have already done it and begun the much needed experimentation. It will not be long before the excuse that syllabi and college entrance examinations compel adherence to traditional methods will be wholly beside the mark, especially in the schools supported by public funds. The spirit of physics is not composed of Newton's laws of motion, Boyle's law, *et al.;* and this spirit cannot be imparted to pupils by imposing on them these ideas, arranged in a logical system, to be learned by fair means or foul. The spirit of physics is the intuition of universal relatedness, which the pupils already have; and the function of physics teaching is to assist them in making that intuition concrete and in proving its validity. It took physics three hundred years to do this, and we must not expect the pupils to do it in twenty minutes. We must partake of the naïve skepticism of the Sunday school boy who bet that even the Almighty could not make a two-year-old calf in ten minutes. The remaining chapters present one way in which this spirit of physics may be cultivated and made concrete among the pupils, without inhibiting the possibility of transferable discipline. There are many

other possible ways of doing this, and it is hoped that others will be discovered in the near future.

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CHAPTER X

THE ORGANIZATION OF THE COURSE

91. Simplicity and Unity. — Opinions differ as to whether the class work in physics should be organized about the laboratory work as a center, or *vice versa*. The question has been much debated whether laboratory experiments should verify and exemplify facts and laws first discussed in class, or whether the facts and laws should be first met with in the laboratory and discussed in class afterwards. The conclusion of this debate seems to be that it is six to one and half a dozen to the other; if the facts and laws are first discussed in class, the pupils do the laboratory work more intelligently; and if the laboratory precedes, they understand the class work better. But, while there are differences of opinion on this matter, all are agreed that the class work and that of the laboratory must be knit into a well coördinated, simple and unified course.

For this reason the first important question to be settled before devising a suitable course in physics is How can it be arranged to secure simplicity and unity? In answering this question, much help can be secured

from a study of the history of physics, as outlined in Chapters V and VII. It was there shown that the great unifying idea in physics has been the idea of energy, and that unity was found in this idea because of the discovery of the constant relationships among the units of energy, the foot pound, the British thermal unit, and the watt-second (or the erg, the gram calorie, and the watt-second). Hence the concept of energy may well serve as the unifying idea of the course.

That this concept also gives the simplest interpretation of physical phenomena is also evident for the following reasons: first, as Poincaré shows,[1] "though other systems of mechanics are possible, their equations would be less simple than those of the accepted mechanics." In like manner its greater simplicity is the basis for our choice of Euclidean in preference to non-Euclidean geometry. In other words, simplicity is one of the leading criterea of the truth of scientific systems. Second, the central hypothesis of the Newtonian mechanics is that of central forces. However brilliant the success of this hypothesis in celestial mechanics, it leads to vast complexity when applied to physical mechanics. In fact, it may be said to have broken down completely in its efforts to describe physical phenomena, particularly irreversible processes. It also leads one to seek to try

[1] Poincaré, *Science and Hypothesis*, p. 77 (Science Press, 1905).

to invent mechanisms by which natural phenomena may be supposed to be produced, and this has led away from true physics, which seeks only to determine the quantitative relations among the elements of phenomena, into speculations about "centers of force," the "nature of atoms," and the like.

It has been urged that these speculations delight students and set them to thinking. This is true, provided you call speculation thinking. The Greeks were fond of this sort of thinking, and the scientific value of their Platonic thought has already been sufficiently explained. It is much more aristocratic and lazy to speculate than it is to find out by patient experimenting just what things will actually do. Besides, as Poincaré shows:[1] "When a phenomenon obeys the two principles of energy and of least action, it admits of an infinity of mechanical explanations. But this is not enough: for a mechanical explanation to be good, it must be simple; for choosing it among all which are possible, there should be other reasons besides the necessity of making a choice. Well, we have not as yet a theory satisfying this condition and consequently good for something. Must we lament this? That would be to forget what is the goal sought; this is not mechanism; the true, the sole aim is unity."

[1] Poincaré, *Science and Hypothesis*, p. 124.

92. **Mechanism.** — Most teachers will object to abandoning the attempt to teach high school pupils the latest theories of the mechanism of atoms and the kinetic theory of gases. It will be urged that men like Maxwell and Kelvin made free use of such mechanisms and were led thereby to many fruitful results. This may be perfectly true of expert physicists like those mentioned, although Duhem casts serious doubts on this idea.[1] But whether they use mechanisms usefully or not, experts know how to hold speculation and fact distinct in their minds, and to use the former to discover the latter. The high school pupil does not know this. He memorizes the words that express the theories and the speculations and the laws, and regards them all to be of equal validity and importance. If you doubt this, ask a physics class what happens when you compress a given mass of gas to half its volume, and see how many will attempt to tell what the molecules will do during the action, and how many will tell how the factors whose relations have been determined by measurement will vary. Mechanism is all very well for expert physicists; it is also permissible to indulge in it now and then with beginners, provided they understand clearly that it is all speculation. Let them play Greek once in a while if

[1] Duhem, *La Théorie Physique*, pp. 149 *sq.* (Paris, Chevalier et Rivière, 1906).

they want to, but do not let them be beguiled into confusing this pastime with the serious business of physics. In other words, do not let them confuse speculation with demonstration and objective knowledge.

93. **The Fundamental Principles.** — But if we abandon the idea of trying to penetrate into the mechanism of phenomena by the use of the theory of central forces, what shall be substituted for it? Poincaré suggests the following:[1] "Nevertheless, a day arrived when the conception of central forces no longer appeared sufficient. What was done then? The attempt to penetrate into the detail of the structure of the universe, to isolate the pieces of this vast mechanism, to analyze one by one the forces which put them in motion, was abandoned, and we were content to take as guides certain general principles, the express object of which is to spare us this minute study.

"Suppose that we have before us any machine; the initial wheel work and the final wheel work alone are visible, but the transmission, the intermediary wheels by which the movement is communicated from one to the other, are hidden in the interior and escape our view. Do we say that it is impossible for us to understand anything about this machine, so long as we are not permitted to take it to pieces? You know well we do not, and

[1] Poincaré, *l.c.*, p. 173.

that the principle of the conservation of energy suffices to determine for us the most interesting point. We easily ascertain that the final wheel turns ten times less quickly than the initial wheel; since these two wheels are visible, we are able thence to conclude a couple applied to the one will be balanced by a couple ten times greater applied to the other.

"Well, in regard to the universe, the principle of the conservation of energy is able to render us the same service. This is also a machine, much more complicated than all those of industry, and of which almost all parts are profoundly hidden from us; but in observing the movement of those that we can see, we are able, by the aid of this principle, to draw conclusions which remain true whatever may be the details of the invisible mechanism which animates them.

"The principle of the conservation of energy, or the principle of Mayer, is certainly the most important, but it is not the only one; there are others from which we are able to draw the same advantage. These are:—

"The principle of Carnot, or the principle of the degradation of energy.

"The principle of Newton, or the principle of the equality of action and reaction.

"The principle of relativity, according to which the laws of physical phenomena should be the same, whether

for an observer fixed, or for an observer carried along in such a motion.

"The principle of the conservation of mass, or principle of Lavoisier.

"I would add the principle of least action.

"The application of these five or six general principles to the different physical phenomena is sufficient for our learning of them what we could reasonably hope to know of them."

These, then, are the principles in modern physics which supersede the hypothesis of central forces in Newtonian physics. It is perfectly true that in acquiring these principles physics traveled via the doctrine of central forces. But is that the shortest and quickest road? Now that these principles have been established, cannot the beginner be led to acquire some realization of their meaning in a more direct way? Perhaps if the hypothesis of central forces had not yielded such marvelous results when applied by Newton to celestial mechanics, these principles might have been established by physics in a more direct manner by following the lead of Stevin, Galileo, and Huyghens. The brilliancy of Newton's achievements in treating a frictionless system may have given men an exaggerated idea of their value in treating systems with constraints.

94. **Objectivity Necessary.** — Be that as it may, the

function of the physics teacher of to-day is to assist the pupils in acquiring the benefits of physics to the fullest possible degree in the short time at his disposal. He will surely do this most effectively if he will aim directly at the big and dynamic things in modern physics. In doing this, the closer he sticks to what is fundamentally real and objective, the more likely he will be to succeed; and "The sole objective reality consists in the relations of things whence results the universal harmony. These are objective because they are, will become, or will remain, common to all thinking beings."[1] "Besides, if we study mechanics, it is to apply it; and we can apply it only if it remains objective. . . . It is therefore, above all, with the objective side of the principles that we must be familiarized early, and that can be done only by going from the particular to the general, instead of the inverse."[2] Finally: "When we say force is the cause of motion, we talk metaphysics; and this definition, if one were content with it, would be absolutely sterile. For a definition to be of any use, it must teach us to measure force; moreover that suffices; it is not at all necessary that it teach us what force is *in itself*, nor whether it is the cause or the effect of motion."[3]

To summarize: 1. The really objective things in

[1] Poincaré, *The Value of Science*, p. 140.

[2] Poincaré, *Science and Hypothesis*, p. 100. [3] *Ibid.*, p. 73.

physics are the quantitative relations among phenomena, as determined by measurement. 2. The pupil shows the true spirit of physics when he becomes absorbed in its objective side, *i.e.* in determining numerical relations among phenomena. 3. Throughout the course the pupil must remain close to the objective side, *i.e.* to the relations that can be measured, and must proceed from special cases to more general relations. 4. Definitions, to be of any value, must teach us how to measure the thing defined.

95. **Definitions.** — These ideas, together with those developed in Chapters V to IX, point out the way to organizing a really vital course in physics. There are many ways of doing this, but the following plan of treating the energy principle may serve as an example of the general method of going at it.

Since the essence of the work is to consist in the measurement of related factors, it is necessary at the start to define the factors whose relations are to be determined. This means that we must tell how they are measured. This should not, however, be done in the usual way; namely, by an abstract discussion of the metric system and the mere statement of the definitions of the absolute units. As Poincaré points out:[1] "How can we find a concise statement which

[1] Poincaré, *Science et Méthode*, p. 139.

will satisfy at once the inviolable rules of logic, our desire to understand the place of the new idea in the ensemble of science, and our need of thinking in images? Most frequently this cannot be done, and that is why it is not enough to state a definition; it is necessary to prepare the way for it and to justify it. . . . A definition is presented to us as a convention; but most people revolt if you try to impose it on them as an *arbitrary* convention. . . . Usually mathematical definitions are veritable edifices constructed of many simpler ideas. But why are these elements arranged in this way, when a thousand other arrangements are possible? Is it by caprice? If not, why has this particular arrangement more right to live than all the rest? To what need does it respond? How was it foreseen that it would play an important rôle in the development of science? Is there in nature any familiar object which is, as it were, an indefinite and gross image of it?"

Poincaré then shows that if you wish to make satisfactory answer to such questions, you will have to explain the analogies that have led to the definitions, and then concludes: "If the definition is sufficiently rigorous to please the logician, its justification will content the intuitive. But it is better to do still more. Whenever it is possible, the justification will precede the statement of it, and will prepare the way for it; the student will be

led to the general statement by a study of several particular examples."

96. **How Define Work?** — If we follow this excellent advice, we will begin the discussion by preparing the way for a definition of work — a definition consisting of a statement of how work is measured. Since we must at the start keep close to general experiences and seek to produce a fork-road situation in which thinking begins, we might well begin in some such way as this: Is it more work to climb straight up a tree than to climb up to the same height on a ladder? Why? Is it more work to climb to the third floor up a vertical fire escape or to walk up the stairs to the same height? Why? Does it require more work to slide a cake of ice up an inclined plane into an ice house than it does to lift it vertically to the same height? Why? What do you mean by work? Are scrubbing floors, painting houses, sawing wood, planing boards, pumping water, plastering walls, filing metals, all forms of work? What are their common elements that make us classify them as work?

Having made it evident that work consists in pushing, pulling, or lifting something for some distance against resistance, we show that in order to answer the questions first raised, we must needs *measure* work. If by some such procedure as the foregoing a *need* for measuring work has been created, the pupils will have

no difficulty in following an argument of this kind: Work is done when one brick is lifted one foot. How much more work is done when two bricks are lifted one foot? When three bricks are lifted one foot? How much more work is done when one brick is lifted two feet? When two bricks are lifted two feet? The amount of work done thus depends on the number of bricks lifted and the distance through which they are lifted. If the bricks weighed nothing, it would be no work to lift them. It is, then, the weight and the distance that determines the amount of work. But weight is measured in pounds and distance is measured in feet, so work is measured by the product of pounds weight times feet.

This idea may then be extended to horizontal work by showing that horizontal forces may be replaced by weights on the ends of strings that pass over pulleys, or by pulls measured by spring balances. Thus a definition of force as anything that may be *measured* by a spring balance in pounds weight (or grams weight) is finally reached.

It then remains to show that the force and the distance must be measured in the same direction. This may well be taken for granted at the start, and explained after some of the experiments have been done.

97. **Problems that Require Measurements.** — Having now defined *work*, by showing how it is measured, we

are ready to take up the problems proposed. It will be noted that these are of the sort that *cannot be answered without measurement.* In order to answer them definitely, recourse must be had to experiment. Since a block of ice and an ice house are not available, we let a block of wood represent the ice, and a sloping board the inclined plane, and pull the block up the plane uniformly with a spring balance. The number of pounds force indicated by the balance multiplied by the number of feet through which the block is pulled along the plane measures the work done. The weight of the block multiplied by the height of the plane measures the work done in lifting it vertically. Many pupils are surprised to see how much greater the former is than the latter.

Why does it take so much more work to pull the block up the plane? Can this difference in the amounts of work be lessened in any way? Try placing the block on wheels. This expedient brings the two amounts of work nearer together. Cover the plane with a strip of glass; further improvement results. We thus see that as we perfect the machine the two amounts of work grow more nearly equal. We may conclude that if we could make an ideally perfect machine, the two would be equal.

98. **Efficiency.** — We are now ready for more definitions. The useful work done by the machine is

called the *output* or work out; in this case, it is the product of the weight and the vertical height of the plane. The actual work done is called the *input* or work in. The efficiency of the machine is the fraction obtained by dividing the output by the input. Since in practical cases the input is greater than the output, the efficiency of the inclined plane is less than unity.

We may now ask whether a wheel and axle, a set of pulleys, or a combination of levers might be used with greater success in lifting ice into the ice house. This again is a problem that cannot be answered without making measurements. We have to measure the efficiencies of the particular wheel and axle or the particular pulleys that it is proposed to substitute for the inclined plane. This investigation may lead to a comparison of various sets of pulleys, a study of how they may be improved, leading to the same conclusion as before; namely, in the ideal case, the input and the output would be equal, but in every real case the input is greater than the output and the efficiency is less than unity.

99. **Summary. The Work Principle.** — This method of treatment fulfills the pedagogical and scientific requirements that were discussed in the previous chapters. It begins with the daily experiences: it produces a situation in which a problem is defined; the problem will

generally be significant if the teacher has not tried to tell the answer in advance; the answer is unknown to the teacher and cannot be obtained without measurements; the definitions of the units of measurement are justified in advance; the ideal case or law is found by a series of approximations; the laboratory assumes its correct function as the place in which to seek information that cannot be secured elsewhere, and the whole discussion leads somewhere in physics, — namely, to the work principle, which is repeated and encountered in several different ways.

An admirable conclusion of this discussion consists in showing Galileo's pendulum experiment, and drawing as many conclusions from it as the pupils are able to draw. Such are: in measuring work, force and distance must be measured in the same direction; the center of gravity seeks the lowest level; the idea of inertia; work done by or against gravity depends on vertical difference of level and not on the path from one level to the other.

After the idea of the work principle is well grasped in its relations to simple machines, we may pass on to work done by fluids. If a water-power plant exists in the neighborhood, a visit to it would probably be the most effective starting point. If not, secure several small water motors, and ask the class which is the best one. This leads again to a necessity for measurements, and for methods of

measuring work done by fluids and that done by motors. It may lead to a study of the conditions of *maximum efficiency* of one motor, and those of perfecting the machine so as to increase its efficiency. This idea of maximum efficiency is valuable as giving a first inkling of the meaning of the principle of least action. The final result of it all is, the output is greater than the input, or the efficiency is less than unity.

100. **Problems in Heat.** — Since the example we are trying to describe is that of the presentation of the energy principle, we pass over the treatment of the other principles of fluids and continue with those ideas in the subject of heat which bear on this immediate question. In heat it may be well to begin with some such question as this: Which is the most efficient kettle, one of iron, one of aluminum, one of enameled ware, one of copper, or one of tin? Or which is the most efficient kind of a gas burner, a Bunsen burner or one on the kitchen stove? These questions define problems that are significant to most pupils because close to the daily life. They also make measurement necessary, and prepare the way for the definition of the units of quantity of heat (the British thermal unit or the gram calorie). The answers, however, come out, not as true efficiencies, but in terms of British thermal units per minute or in gram calories per cubic foot of gas. To reduce them to

true efficiencies, we must find the number of gram calories per cubic foot of gas. This leads to the idea of thermal efficiency as the ratio of useful heat retained to total heat used. This ratio is again found to be a fraction whose value is less than unity. This fact may lead to a study of the conditions under which the efficiency may be increased, if desired.

The steam engine furnishes probably the best approach to the treatment of the relations between heat and work. Its history is particularly instructive, and its present importance to the world's work is always a fruitful topic for discussion. The steam engine depends upon coal, so the value of coal supply and the present active campaign for conservation of natural resources are useful means of connecting the problem with the daily life. The real problem here is: Are we wasting coal? Is the steam engine as efficient as it might be?

The workings of the old engines, like Newcomen's, should first be described, and the faults in their construction noted. Then explain Watt's devices for saving heat and increasing the efficiency, noting particularly his recognition of the need of a hot body and a cold body if work is to be secured by heat. Watt's best engine, however, consumed ten pounds of coal per horse-power hour. Since Watt's time, engines have been improved until now the locomotive consumes about three pounds

of coal per horse-power hour; while a good marine engine consumes about one pound for the same amount of work.

Is this the limit of the possibilities in the case? To answer this we must know what the true efficiency of the engine is. Pounds of coal per horse-power hour is not true efficiency because the input and the output are measured in different units. By burning coal in a calorimeter, we can find out how many British thermal units of heat are liberated by burning a pound of coal. This enables us to state our efficiency as a ratio between horse-power hours and British thermal units; but still the units are not the same. Is it possible that these two quantities may be reduced to the same units? Is there any constant relation between the British thermal unit and the foot pound.

101. **Definition of Energy.** — We have now prepared the way for Joule's experiment on the mechanical equivalent of heat, and for the statement of the result. It is important here to make clear the real meaning of this result. The experiment consists in doing a certain number of foot pounds of work on a machine and getting a certain number of British thermal units in return. The result is important because it shows that when we divide the number of foot pounds of input by the number of British thermal units output, we always get practically

the same number, namely, 778. The meaning of this fact can be grasped by considering the following analogous case.

If we measure the edge of the table in inches and in centimeters, and divide the number of centimeters by the number of inches, we get the result 2.54 centimeters per inch. Whenever we measure the *same length* in terms of these different units, and divide the number of centimeters by the number of inches, we get the same constant ratio, namely, 2.54. The constancy of this ratio between the units indicates that we have been measuring the *same thing* in terms of the different units. In like manner, the constancy of the ratio between the foot pound and the British thermal unit indicates that in these experiments of Joule's he was measuring the *same thing* in terms of different units. This same thing is what we call *energy*.

Having thus prepared the way for the definition of energy, we may state it in such a way as this: energy is measured in foot pounds or in British thermal units. This is the only definition that has any real value in physics. To say that "energy is ability to do work," is to talk metaphysics. It is a perfectly useless statement both for the pupil and for science. Its only benefit is the negative one of supplying the pupil with a catch phrase which he can repeat glibly when properly

stimulated to do so, and which he can use in examination to cover up effectively his real ignorance. If you begin the course by telling the class that there are two "entities" in the world, matter and energy, and that the quantity of both is eternally fixed, you are trying to make a two-year-old calf in two minutes. Having learned to repeat that statement, the pupil is apt to think he "knows" everything, and further study of physics seems unnecessary. You have given him an "absolute" and "immutable" Platonic thought, and blunted his sensitiveness to a real appreciation of the relatedness of phenomena.

102. The Energy Principle. — But the energy principle is not yet complete. Electricity remains to be conquered. Here again it is well to begin with some such question as this: Here are several small motors; which is the most efficient? Your result will be obtained in foot pounds per watt-second. This is no real efficiency, since the units are not the same. Is it possible to reduce them to the same unit? Joule's experiments with the calorimeter give a constant relation between the British thermal unit and the watt-second, namely, 1 British thermal unit = 1055 watt-seconds. The constancy of this ratio again means that we have been measuring the *same thing* in terms of different units; and we expand our definition of energy to read: energy is the thing that is measured in

foot pounds, in British thermal units, or in watt-seconds. The energy principle may then be stated in some such way as this: energy input = energy output. Or, if you prefer, foot pounds + British thermal units + watt-seconds input = foot pounds + British thermal units + watt-seconds output.

103. **Some Objections.** — This method of treatment will shock most physics teachers because it is *illogical.* How can pupils measure watt-seconds, they say, unless they have had the watt carefully defined by *logical* steps beginning with the unit charge of static electricity, which is the *simplest element*, and proceeding thence to build up the idea volt with the help of this unit charge and the idea of work previously defined in an equally logical manner. The reply is simple. Give them an ammeter and a voltmeter and a real motor to test and see if they can do it. And do not forget that a definition must be justified *in advance* of its statement, and that a logical setting forth of a process is possible only *after* the result has been attained by less formal and more intuitive processes. The essential thing is to produce a situation in which thinking begins; when this has been accomplished, the direction of the thinking into useful channels is not so difficult.

Objection is also made to the method of presentation here suggested as the best, on the ground that it is

basely commercial and leads nowhere in physics. This objection is perfectly valid when the work is so done as to make the statement true. But when practical applications and the measurement of the efficiencies of real machines is merely the significant starting point for the acquisition of a tolerably definite and concrete meaning of the doctrine of energy, who will say that the means do not justify the end? The more so, if transferable discipline and an ideal of scientific method has also been secured in the process. And although this method of treatment is here urged as the only one that will enable physics to hold its honorable place in a system of democratic education, it is more than probable that it may be a far better system of training prospective physicists than the system now in use. Experiment alone can settle this question, and until such experiments have been made, it is useless to condemn this method because of the repugnance which all feel toward changing well-established habits of thought and action.

104. **Optics.** — As a second example of the method of treatment demanded by the working hypotheses here set forth, consider the subject of optics. Here the unifying idea cannot be that of energy, since the treatment of optics from this point of view has not yet been fully worked out. Unity may be secured here in numerous

ways. We may ask: what does light do for me, and how does it do it? The personal uses of light and of optical instruments in seeing things and in increasing our powers of vision become the center of the course. It is of course perfectly useless to begin this study with a statement of the theories of ether and electromagnetic vibration, or with discussions of the "nature of light." Such problems belong to metaphysics; physics is concerned with such relations among the elements of phenomena as can be determined by observation and experiment.

One of the most useful things that light does for us is to enable us to distinguish objects from one another and to judge of their relative positions, sizes, and motions. How does it do this? How do we detect differences in direction and in size? The sun and the moon appear to be of the same size; a fly on the window ten feet away appears just as big as a man half a mile away. To one looking along a straight railroad track, the rails appear to be closer together at a distance than near by, although they are the same distance apart everywhere. There is thus a difference between real size and apparent size; in what does this consist?

If the work in energy as previously described has preceded the work in light, the pupils should be able to grasp the problem as thus defined. If not, the problem may be defined more concretely by a study of cameras.

Do all cameras placed at the same distance from an object take pictures of the same size? Can you take a picture without a lens? Are all such pictures of the same size? If not, why not? What conditions determine the size of the picture? The classroom experiment with the pinhole camera on a large scale is an effective source of motivation here.

From working with pinhole and other cameras, the pupils may soon be led to see that the visual angle is determinative of the apparent size of an object, and that the image always subtends the same angle at the center of the opening or the lens; hence the light travels in straight lines. The visual angle of a given object at a given distance is fixed; the angle subtended by the image is always equal to the visual angle of the object, and so the actual size of an image for fixed object and object-distance depends only on the distance of the image from the pinhole or lens. This constancy of the visual or lens angles of the object is of fundamental importance and may be made the key to the problems of vision, thus giving unity to the treatment of this topic.

The other factor in a discussion of vision is that of focal length. The image in a pinhole camera is blurred or fuzzy, because each point of the object sends a cone of light through the pinhole, and this cone makes in the image a spot instead of a point. The image is thus

composed of an array of overlapping spots instead of points; and it is, therefore, blurred. A lens that is thicker in the middle than it is at the rim reduces these spots in the image nearly to points, and so the image becomes clearer, provided the screen that receives the image is placed at one particular position called the focus. The size of the image in this position is the same whether the lens is used or not; the lens merely makes the image clearer. When the difference in thickness between the middle and the rim of the lens is large, the focus is nearer the lens; and when this difference is small, the focus is farther off. Hence long focus lenses produce larger images of the same object at a given distance than do short focus lenses, although the visual or lens angles are the same for each.

105. **Theories Unnecessary.** — It will be noted that this discussion requires neither the wave theory nor the ray theory of light. It enables the pupil to acquire many useful, consistent, and definite ideas as to vision and cameras. On this foundation it is easy to proceed to a simple and rational explanation of how the simple microscope and the telescope enable us to increase the apparent sizes of objects, of the faults of eyes, and even of the ideas of resolution. If the class is interested in this work, the problem of finding how accurately the lens reduces the spot of the pinhole camera to a point

leads readily to easy discussions of chromatic aberration, spherical aberration, and astigmatism. In other words, although the discussion *starts* with the immediate phenomena of daily life, or with the commercial camera, the upper limit in physics at which the work must stop is placed only by the limitations of the teacher, the pupils, and the time.

Objection will be made to the foregoing outline on the ground that it dispenses with the mechanism of image formation, and tries only to develop clear ideas about those relations between objects, images, and focal lengths which are amenable to observation and measurement. Those who feel this way about it are urged to produce diagrams and explanations of image formation such that a beginner can understand them. It is well enough to introduce the wave theory at the end, after the pupils have gathered enough facts and experience to appreciate it, but to hang the whole discussion from the start on the wave theory is a genuine case of putting the cart before the horse.[1]

106. Light and Electricity. — Some of the work in light may well be closely annexed to that in heat and electricity by studying the efficiencies of various sources of illumination, such as candles, kerosene, gas, and vari-

[1] For a complete working out of the ideas here presented for a full year's work, the reader is referred to the Mann & Twiss *Physics*, 2d ed., Part I (Chicago, Scott, Foresman & Co., 1910).

ous kinds of electric lamps. This extension necessitates merely the addition of the idea of photometry. While it leads to no real efficiency, it gives interesting results as to the cost of the various kinds of illuminants per candle-power hour. There is a great deal of very valuable laboratory work that may profitably be associated with work on this subject.

The topic of color is always of interest if approached concretely by showing a group of variously colored objects in differently colored lights. The tri-color printing processes are always a prime source of objective attention.

107. **Remember the Aim, Unity.** — Enough has been said to make clear the method of treatment called for by the working hypotheses of the new education. It must not be inferred that the above outline of this method as applied to the energy principle and to optics is an outline of an entire year's course. Far from it. Other principles and phenomena need treatment also; though it is, of course, clear that all of the principles which Poincaré mentions (see p. 223 *ante*) cannot receive treatment in a high school course. If the teacher remembers that physics does not consist of a large number of detached fragments of facts and laws, and that elementary physics is not a totally different species from physics, but is the child which grows later into the man

physics, he should be able to organize a course having unity, significance, simplicity, and real value in the lives of those who must enter the ranks of the world's workers.

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CHAPTER XI

The Laboratory Work

108. Current Ideas of Laboratory Work. — The ideas that were prominent when laboratory work in physics began to be introduced into the schools have been treated in Chapter III. The demand for individual work by the pupils was the outgrowth of the general demand for object teaching. Since "seeing is believing," the children should see for themselves that the "facts and laws of elementary physics" were actually what they were supposed to be, namely, "true." The fundamental idea was that the actual handling of the apparatus and the making of the measurements would make the law more real and concrete to the pupil; and, therefore, that he would be able to grasp its meaning better and to apply it with greater intelligence.

That this idea is perfectly true, whenever the statement just made correctly describes the actual work done, no one will for one minute deny. Whenever the laboratory work is so conducted as to make a thing concrete to the pupil, the desired result follows. This was undoubtedly the case with much of the work done under the

guidance of books like that of Gage. Most of the experiments which he uses are well calculated to render the ideas that they exemplify concrete to the pupils.

But as the high school physics became universityized and as the laboratory facilities increased and equipment became more plentiful, the experiments became more elaborate, more accurate, and, what was worse, more abstract. Thus the Harvard *Descriptive List* in 1886 was designed: "1st, to train the young student by means of tangible problems requiring him to observe accurately, to attend strictly, and to think clearly; 2d, to give practice in the methods by which physical facts and laws are discovered; 3d, to give practical acquaintance with a considerable number of these facts and laws, with a view to their utility in the thought and actions of educated men."[1] In 1897 the statement of the Harvard laboratory requirement read:[2] "The pupil's laboratory work should give practice in the observation and explanation of physical phenomena, some familiarity with methods of measurement, and some training of the hand and the eye in the direction of precision and skill. It should also be regarded as a means of fixing in the mind of the pupil a considerable variety of facts and principles." Again, after discussing the experiment

[1] *Ante*, p. 54.

[2] Smith & Hall, *Teaching of Chemistry and Physics*, p. 272.

with the parallelogram of forces, Professor Hall says:[1] "The object of the experiment in this case is to make the pupil realize the meaning of the law, while giving him an opportunity to exercise, and by the final result to test, his skill."

It will be noted that the idea of "utility in the thought and actions of educated men" has disappeared, and in its place the pupil is given a chance to "test his skill" in making accurate measurements and to "realize the meaning of the law." It will also be noted that the first purpose was "to train the young student to observe accurately and to think clearly."

The latest expression of opinion on this subject comes from Coleman, in his essay on the Purpose and Method of Experimental Work in Physics.[2] The purpose of the work is thus set forth: "Its specific purpose is to enlarge the pupil's acquaintance with the facts of the subject at first hand. . . . The laboratory experiment is not a proof of the law, but an aid to the right understanding of it. . . . If it has only such connection with the work of the classroom as the pupil makes on his own initiative, it will have very little value indeed. . . . The text and the experiments are different lines of ap-

[1] Smith & Hall, *l.c.*, p. 279.

[2] Coleman, *School Science and Mathematics*, Vol. XI, p. 816, December, 1911.

proach to the same goal, namely, an understanding of physics. . . . It is the business of the elementary laboratory to afford opportunity for gaining a selected and directed experience under good working conditions. . . . The laboratory experiment is predetermined and fixed. It follows a set of written or printed directions, from which the pupil can rarely depart with any profitable result."

This statement of the case gives the present generally prevailing ideas of the use of the laboratory work. In brief, the laboratory is the place where the students get predetermined experiences, cunningly devised to make the law intelligible to them and to help them to keep it in mind; to the end that they may "understand physics."

109. **Current Ideas are Inadequate.** — This purpose of the laboratory work is so generally accepted that there can be little doubt that it is correct as far as it goes. In the light of the discussions of the previous chapters, we may very reasonably question its adequacy. Is that all the laboratory work is for? If so, is the game worth the candle? Is the "understanding of physics" which the pupils actually get from it worth the time and labor and expense required by the work? If we grant that some pupils gain an understanding of physics because of it, we must also grant that many more do not do this.

And anyway, an understanding is an intellectual thing, while in ideals of method — which are the transferable factors — the emotional elements are by far the most important. What is the emotional reaction of the majority of the pupils, both of those who take physics and those who avoid it? Why do they call the experiments "stunts"? Why do they aim at the "correct" results, predetermined and fixed, instead of at useful experience?

The answers to these questions are not hard to find. Few pupils really want to know the facts and laws that the experiments are devised to make clear to them. And why should they, when the uses of these are not explained until the law is "understood"? Unless the problem which they are trying to solve has been defined from a forked-road situation that is significant to the pupils, thinking does not begin; and the experiment that is attempted before it is thus justified in advance, or before a need for it is felt, is of little real educative value. Little attention has as yet been given to organizing a course in such a way that the laboratory experiments become necessary, not to illustrate a principle, but to furnish information that is needed in order to solve some problem whose solution the pupils desire to find.

110. **The Result should be Significant.** — Why should not the elementary laboratory be related to the elementary study of physics very much as the advanced

laboratory is to the advanced study of physics? No research student in physics ever makes an experiment just to " see the wheels go round " and have a fact made concrete. He goes to the laboratory for information which he cannot get elsewhere. He has a problem whose solution he is seeking under the impulse of motives of his own, and he needs information which the laboratory alone can supply in order to solve it. He does not know the result in advance, else there would be no *need* for the laboratory work. He does not have a cut-and-dried, predetermined experiment, with detailed directions for its manipulation.

With these points well in mind, turn back to the Harvard *Descriptive List* (p. 56), which has been the model of most of the laboratory lists and manuals since. Consider any of the topics in that list: breaking strength of a wire, elasticity, bending, coefficient of friction, specific gravity of a solid that will sink in water, comparison of masses, and ask yourself whether, if you were a high school pupil again, you would glow with eager enthusiasm to know the results of any of these experiments for the mere sake of the knowledge. Why should the pupil be keen to know the breaking strength of a wire, or the coefficient of friction between a block of wood and a board? To what inherent need of his does the experiment minister?

Or again, take any laboratory manual and open it at random; read the experiment through, and ask yourself why a pupil should be enthusiastic over it or should even want to know the result. There is no answer to this question, — unless it be that he shouldn't. The experiments are not designed to furnish information that the pupil needs in order to solve a problem that is significant to him. They are designed simply and solely to furnish a concrete basis for his appreciation of some tidbit of physics. He must go through the motions indicated, not to satisfy his spirit of wonder, but to fulfill to the letter some "requirement" of the school system. The process is somewhat like compelling a hungry boy to stuff his blouse with apples in order to make him appear plump and hearty, instead of letting him eat them.

For example, on opening a book at random, the following appears: "To study the effect of change of pressure on the volume of *a gas*, or to verify Boyle's law." Then follows the usual description of apparatus, procedure, discussion. This latter consists of the following information, dear to the hearts of the pupils, and well calculated to inspire them with reverence for the methods of science: "It is a law of mathematics that when the product of two variables (*sic!*) is constant, the two quantities are inversely proportional. Is the product $P \times V$ constant, at least as far as the sure

figures? Another way to consider this is to notice whether the pressure is one half as great as at first, when the volume is two times as great; one third as great when the volume is three times as great, etc." Interesting, no doubt, and valuable as physics; but what problem in life does it help *him* to solve?

The result of this sort of work is thus described by Poincaré:[1] "There is one thing that strikes me: it is how many young people who have received a high school training are far from being able to apply the mechanical laws that have been taught them to the real world. It is not that they are incapable of doing this; they never think of it. For them the world of science and that of reality are separated by a yawning chasm. It is not rare to see a well-to-do man, probably a bachelor, riding in a carriage and imagining that he is helping it to go by pushing forward on the floor, notwithstanding the fact that this shows a failure to apprehend the principle of action and reaction."

111. **The Real Purpose.** — The real purpose of the laboratory and the inadequacy of the idea that it is the place to render ideas concrete merely by presenting a series of ingeniously devised objects is thus pointed out by Dewey:[2] "Since the *concrete* denotes anything ap-

[1] Poincaré, *Science et Méthode*, p. 146.

[2] Dewey, *How We Think*, pp. 139 *sq.*

plied to activities for the sake of dealing effectively with the difficulties that present themselves practically, 'beginning with the concrete' signifies that we should at the outset make much of *doing;* especially, make much in occupations that are not of a routine and mechanical kind and hence require intelligent selection and adaptation of means and materials. We do not 'follow the order of nature' when we multiply mere sensations or accumulate physical objects. If physical things used in teaching number or geography or anything else do not leave the mind illuminated with recognition of a *meaning* beyond themselves, the instruction that uses them is as abstract as that which doles out ready-made definitions and rules; for it distracts attention from ideas to mere physical excitations.

"The conception that we have only to put before the senses particular physical objects to impress certain ideas upon the mind amounts almost to a superstition. The introduction of object lessons and sense training scored a distinct advance over the prior method of linguistic symbols, and this advance tended to blind educators to the fact that only a halfway step had been taken. Things and sensations develop the child, indeed, but only because he *uses* them in mastering his body and in the scheme of his activities. Appropriate continuous occupations or activities involve the use of

natural materials, tools, modes of energy, and do it in a way that compels thinking as to what they mean, how they are related to one another, and to the realization of ends; while the mere isolated presentation of things remains barren and dead. A few generations ago the great obstacle in the way of reform of primary education was belief in the almost magical efficacy of the symbols of language (including number) to produce mental training; at present, belief in the efficacy of objects just as objects, blocks the way. As frequently happens, the better is an enemy of the best."

112. **Conditions for Vital Work.** — Since the current forms of laboratory practice are inadequate to achieve the purposes of physics teaching, as set forth in Chapter IX, what kind of work would be more profitable? If we recall the conditions under which the specific discipline of physics may be made general, it will not be difficult to reorganize the work without throwing away entirely the equipment which the laboratories already have for their supposed purpose of "fixing in mind the facts and laws of elementary physics." The conditions to be fulfilled are these: (1) An ambiguous or forked-road situation must be produced in which thinking begins and which leads to the definition of a problem significant to the pupil. (2) The problem must be of such a nature that its answer cannot be obtained without

making measurements or at least experiments in the laboratory.

113. **Suitable Problems.** — It is not difficult to meet these conditions, once the teacher's mind is freed from the incubus of the "facts and laws of elementary physics" as set forth in lists backed by the "authority of official utterance." Since the first problems must of necessity arise from the pupil's daily experiences, they will be different in different localities. As samples of the kind of problems that may be used to advantage in fulfillment of the conditions stated, the following list is appended as suitable for use with the topics treated in the last chapter. This is not the only possible list; an infinite number of others are equally possible and perhaps far better. It is added simply to suggest the kind of problem that may prove adequate.

1. Does it require more work to slide a cake of ice up an inclined plane than it does to lift it vertically through the same height? If so, how much more?

2. How can you alter the inclined plane to increase its efficiency?

3. Can the ice be lifted into the ice house more efficiently with a set of pulleys than with an inclined plane?

4. Does it require more work to lift a stone with a crowbar than to raise it by hand through the same height? How much more?

5. Is a wheel and axle more efficient than a set of pulleys for hauling water from a well? How much more?

6. Is a force pump more efficient than a lift pump? How much?

7. Which of two water motors is the more efficient? How much more? Does the efficiency of the motor depend on the speed or on the load? What are the conditions of maximum efficiency?

8. Is a given motor more efficient on a tap in the basement than on one on the third floor? Is there any relation between pressure and efficiency?

9. Which is the most efficient gas burner, a Bunsen burner or one from a gas stove?

10. With a given burner, which kind of kettle is most efficient: one of iron, one of tin, one of enameled ware, or one of aluminum? How much more?

11. Does a given kettle containing a given quantity of water at tap temperature come to a boil in less time when the cover is off than it does when the cover is on? How much more?

12. If it takes fifteen minutes for an uncovered kettle containing one kilogram of water at tap temperature to come to a boil, how much water will boil away in five minutes? From the data obtained compute the heat vaporization of water. Correct the result with the data obtained in problem 11.

13. Is the heat equivalent of the city gas up to standard (600 B. T. U. per cubic foot)?

14. Which kind of coal in your town gives the greatest number of heat units per pound?

15. Is it cheaper to distill water with a laboratory still, burning gas at eighty cents per thousand cubic feet, or to buy distilled water from the druggist at ten cents a gallon? How much cheaper?

16. What is the thermal efficiency of the laboratory still? How can it be increased?

17. Which radiates more heat per watt hour, a carbon or a tungsten lamp? How much?

18. Which of two small electric motors is the more efficient? How much more? Does the efficiency depend on the speed or on the load?

19. What is the efficiency of a small gas or gasoline engine?

20. Which costs less per horse-power hour: the water motor, the electric motor, or the gas engine that you have tested? How much?

As samples of the kind of laboratory problems that may prove faithful in connection with the example of a method of treating optics and light, consider the following: —

21. Of two pinhole cameras of the same size, which makes the clearest picture, one with a hole one milli-

meter in diameter or one with a hole two millimeters in diameter?

22. Do different-sized cameras when pointed from a given place at the same object all give images of the same size? Is there any relation between the size of the image and the distance from the center of the lens to the ground glass?

23. Can you construct a telescope with spectacle lenses? How? What is its magnification?

24. Are the object and image formed by a lens closer together when both are of the same size than when one is larger than the other?

25. Is there any relation between distance between object and image, when both are of the same size, and the principal focal length of the lens?

26. Does it cost more per hour to light a room to a given brightness with candles or with oil?

27. Which gives the most light per watt hour, a carbon-filament lamp, or one with a tungsten or a tantalum filament? How much more?

28. In your town is it cheaper to light houses by electricity or by gas? How much?

29. How much more efficient is a Welsbach burner than an ordinary fish-tail gas burner?

30. Is an electric arc lamp more efficient than a tungsten lamp? How much more?

Since there are no laboratory manuals written on the basis here indicated, the following experiments are suggested as typical of the kind of problem that may be found useful in connection with other topics than those discussed.

31. Five cubic feet of lead are used to make the keel of a boat. How much does the lead weigh out of water? Does it sink the boat as far when it is fastened to the keel under water as it does when placed inside the boat?

32. What is the specific gravity of the milk furnished by your milkman? Is it up to standard?

33. How many cubic feet of pine are required to make a raft that would float a one hundred pound boy out of water?

34. Which weighs more, a concrete house or the same house built of brick? How much more?

35. Does the consumer get more gas for his money when the pressure on the mains is high than when it is low?

36. How much ice is melted in a refrigerator when a quart of milk at a temperature of 20° C. is placed in the refrigerator and cooled to 2° C.?

37. How great is the difference in pressure between a water tap on the first floor and one on the third floor? What is the difference in level? Is the difference the same whether one tap is directly over the other or not?

38. What is the velocity of water flowing through a nozzle one quarter inch in diameter under a pressure of twenty pounds to the square inch?

39. What is the efficiency of this hydraulic ram?

40. What is the dew point to-day?

41. Which makes the best lining for a fireless cooker, an air space, felt, excelsior, mineral wool, or granulated cork? Are any of these as good as that of the thermos bottle?

42. How is the siren whistle constructed, and why does it produce its peculiar effect?

43. How long is the sound wave of your own voice?

44. Why is your image in a plane mirror reversed?

45. What makes the "cow's hoof" in a glass half-full of milk when it is placed below and to one side of a candle?

46. How do luxifer prisms and holophane shades help to light up dark rooms? Why is there no color in the light transmitted by them?

47. Which of two electric toasters or curling irons is the most efficient? How much more?

48. Which form of voltaic cell is best for doorbells? Which for telegraph lines? Which for toy motors?

49. Which is the best dry cell on the market?

50. Which is the best kind of wire to use in making electric toasters?

51. Is the resistance of an incandescent lamp greater when it is hot than when it is cold? How much greater?

The foregoing list is not to be taken as a syllabus of experiments for a laboratory course. It is merely suggestive of the type of experimental problem which seems well adapted to the working hypotheses of democratic education. The specific problems used must be different in different localities because the local surroundings are different. Each teacher will have no difficulty in finding plenty of problems of this kind in his immediate environment if he will but remove from his eyes the bandage of prescribed physics which was described in Chapter III.

114. **Engineering or Physics?** — Objection will doubtless be raised to this type of experiment on the ground that it is engineering and not physics. This objection is perfectly valid, as stated before, when the work is of such a kind as to justify the statement that it is engineering and not physics. Nevertheless, this type of work, even though it stops at the engineering stage, is vastly more valuable as a means to general education than is pure physics of the kind specified by college entrance syllabi and examinations. For this work, by beginning with problems of the daily life, makes possible a motivation without which the training given is not likely to be of the transferable kind. A transferable ideal of the scientific method of solving problems is of far more value

in after life to the great majority of the pupils than is a knowledge of the facts and laws of elementary physics,

But whether this type of work stops at the engineering stage or not depends entirely on the skill and ability of the teacher. When he has once secured the attention of the pupils by means of significant problems from the daily life, it is possible to make the more and more abstract and remote problems of physics significant and hence capable of giving transferable training. The converse is, however, seldom true. All teachers are constantly amazed at the inability of the pupils to "apply" their pure physics even to the physical problems of their daily life, to say nothing of their inability to think scientifically on problems outside of physics. No such difficulties appear in schools in which the engineering approach is used effectively; as in the Lewis Institute in Chicago, the High School at Menomonie, Wis., the Industrial High School at New Bedford, Mass., the Ethical Culture School in New York, and the Technical High School in Cleveland, Ohio.

115. **Go from Concrete to Abstract.** — The principles that should guide the teacher in planning and conducting his laboratory work have been thus stated by Dewey:[1] "The interest in results, in the successful carrying on of an activity, should be gradually transferred to the study

[1] Dewey, *How We Think*, p. 140.

of objects — their properties, consequences, structures, causes, and effects. The educative activities of childhood should be so arranged that direct interest in the activity and its outcome create a demand for attention to matters that have a more and more indirect and remote connection with the original activity. The direct interest in carpentering or shop work should yield organically and gradually to an interest in geometric and mechanical problems. The interest in cooking should grow into an interest in chemical experimentation and in physiology and hygiene of bodily growth. This development is what the term *go* signifies in the maxim 'go from the concrete to the abstract'; it represents the dynamic and truly educative factor of the process.

"The outcome, the abstract to which education is to proceed, is an interest in intellectual matters for their own sake, a delight in thinking for the sake of thinking. It is an old story that acts and processes which at the outset are incidental to something else develop and maintain an absorbing value of their own. So it is with thinking and with knowledge; at first incidental to results and adjustments beyond themselves, they attract more and more attention to themselves, till they become ends, not means.

"Abstract thinking, it should be noted, represents *an* end, not *the* end. The power of sustained thinking on

matters remote from direct use is an outgrowth of practical and immediate modes of thought, but not a substitute for them. The educational end is not the destruction of power to think so as to surmount obstacles and adjust means and ends; it is not its replacement by abstract reflection. Nor is theoretical thinking a higher type of thinking than practical. A person who has at command both types of thinking is of a higher order than he who possesses only one. Methods that in developing abstract intellectual abilities weaken habits of practical or concrete thinking fall as much short of the educational ideal as do the methods that in cultivating ability to plan, to invent, to arrange, to forecast, fail to secure some delight in thinking, irrespective of practical consequences.

" Educators should also note the very great individual differences that exist; they should not try to force one pattern and model upon all. In many (probably the majority) the executive tendency, the habit of mind that thinks for purposes of conduct and achievement, not for the sake of knowing, remains dominant to the end. Engineers, lawyers, doctors, merchants, are much more numerous in adult life than scholars, scientists, and philosophers. While education would strive to make men who, however prominent their professional interests and aims, partake of the spirit of the scholar, philosopher,

and scientist, no good reason appears why education should esteem the one mental habit inherently superior to the other, and deliberately try to transform the type from practical to theoretical. Have not our schools been one-sidedly devoted to the more abstract type of thinking, thus doing injustice to the majority of the pupils? Has not the idea of a 'liberal' and 'humane' education tended too often in practice to the production of technical, because overspecialized, thinkers?"

116. **The Psychological and the Logical.** — Examples of one way of doing this have been given in the last chapter. It was there shown how the doctrine of energy might be reached in a course that began with studies of sliding ice into an ice house, of the efficiencies of water motors, teakettles, steam engines, electric motors and heaters, and the like. In like manner the optics began with a discussion of the apparent sizes of everyday objects and led on to the principles of focal length and optical instruments. It need not stop here, if the teacher deems it wise to continue on into interference, diffraction, and resolution.

The study of the fireless cooker has been denounced as devoid of pure physics. But even this useful device, besides leading to the ideas of conduction and convection, may furnish a useful starting point for a study of the relations of emission, reflection, and absorption.

Does it improve the efficiency of the cooker to paint it black inside or to have polished vessels and linings? The important things are that the problems chosen should be such that the pupils want to know the results, and that the experiment is necessary to get the answers. Starting on such a significant basis, the foundations are laid in concrete, and on such a foundation a larger and finer superstructure can be reared than is possible, as is now too often the case, when we attempt to build the cupolas and the dome first, trusting that the concrete foundations will supply themselves somehow.

It is important to note that the method here advocated is the direct converse of that generally in use at present. The present logical method proceeds in the order: principle, demonstration, exemplification in laboratory, application. In the new psychological method the order is: application, problem, solution in the laboratory, principle. To those who insist that there is no distinction between the logical and the psychological orders, this statement of the case is recommended for consideration.

The fundamental distinction between the logical and the psychological is thus stated by Dewey:[1] "All intellectual activity is directed towards an end. The end, therefore, exists in the mind by way of feeling. We do

[1] Dewey, *Psychology*, p. 396.

not know what it is, but we dimly *feel* what it is; and we select material that *feels* congruous with this end, and reject that which *feels* inharmonious. The direction of all intellectual processes by feeling is very commonly overlooked, but it is fundamental. . . . This foregrasp of feeling upon what is not yet intellectually identified and discriminated constitutes a form of intuition. It is a matter that cannot be subjected to rules. After, however, the end has been reached, it is possible for consciousness reflectively to trace the steps and formulate the process. Feeling, when thus reflectively criticised and crystallized into intellectual propositions, gives rise to the rules of the logic of method. Logic, as the science of investigation, must wait upon the actual discoveries of the intellect, which are controlled by feeling. It is reflective and critical, not intuitive and creative; it, therefore, may be taught, while the actual process of discovering new truth can never be imparted. It must follow after, not precede discovery. Logic, in short, only generalizes and crystallizes what was originally existing in the form of feeling."

Though Platonic thought and the doctrine of formal discipline may have proved adequate to guide the aristocratic schooling of the past, they are clearly inadequate to control the democratic education of the present and the future. The chief reason for this is that both ignore

the functions of the feelings and emotions in all really educative processes. In like manner the laboratory work in Physics becomes Platonic and formal when it strives merely to fix in the mind of the pupil the facts and laws of elementary physics as purely intellectual propositions. This process may lead to preparation for the career of a physicist, but it touches only slightly the lives of most of the pupils. It is, therefore, not a vital part of education; since "education is not preparation for life, it is life."

CHAPTER XII

Testing Results

117. Current Forms of Test. — Testing the results of a teacher's work is not only important, but it is also a very illuminating thing both to the pupil and to the teacher. Tests may also exert a powerful influence in determining the nature of the instruction, as when a class has to be prepared to take an examination set by authorities outside the school, and hence not familiar with local conditions. In this case, the teacher is very likely to study the syllabus and the examination papers of the past years and to cram his pupils on them. In such cases the test evidently does far more harm than good.

The questions and problems at the end of each chapter in every textbook are intended to serve the double purpose of giving the pupil some experience in applying the information acquired from that chapter, and of testing the extent and the definiteness of his knowledge. As has been stated, most teachers are continually surprised at the difficulty that most of the pupils have in solving the problems and in answering these questions. If the

teacher happens to give a new type of problem, one not specifically answered in the book, the whole class will usually be floored by it. They "have not had that kind before," and cannot find the formula for it.

In the light of the preceding discussion, the reason for this is not hard to find. Just examine the questions and problems in the current texts and examination papers. This is the sort of thing you find in plenty: —

The volume of a certain mass of hydrogen is 250 c.c. under a pressure of 800 mm. of mercury. What is its volume under standard pressure, 760 mm.?

A weightless rod 70 cm. long rests on a fixed point 25 cm. from one end. To this end a weight of 2 kgm. is attached. What weight must be hung from the other end so that the rod may be horizontal?

If a body moves with uniform velocity of 10 cm. per second for 20 seconds, how far will it have traveled?

A body starting from rest acquires in 5 seconds, with a uniform acceleration, a velocity of 4900 cm. per second. What is its average velocity?

A force of 5000 dynes acts for 10 seconds upon a mass of 250 grams which is free to move and starts from rest. What momentum is imparted to the body? What is its acceleration? How far will it move in 10 seconds?

The weight of a certain mass is 84 gm. What is its weight expressed in dynes?

What is the length of a seconds pendulum whose gravity acceleration is 978 cm. per second per second?

What is the length of a sound wave in air produced by a body whose frequency is 384, the temperature being 20° C.?

A brass rod is 50.8 cm. long at 20° C. and 59.886 cm. long at 98 C. Find the coefficient of linear expansion of brass.

What is the specific heat of a substance whose temperature falls 60° in raising the temperature of the same mass of water 12°?

If the index of refraction from air to glass is 1.5, and light is incident on a glass plate at an angle of 45°, what is the angle of refraction?

How many joules of energy does a kilowatt hour represent?

What is the relative resistance of 90 cm. of platinum wire, .4 mm. in diameter, and the same length of copper wire .33 mm. in diameter, the specific resistance of platinum being seven times that of copper?

What is the velocity of a body having uniformly accelerated motion at the beginning of the tth second?

Solve both equations (2) and (3) for the acceleration a and the time t.

Using the formula for free fall and that for work, prove that the expression of kinetic energy should contain velocity squared.

Two forces of six and eight dynes respectively act at right angles to each other on a mass of 2 grams. What is the resultant force? What is the kinetic energy at the end of 3 seconds?

118. Questions not Significant. — This collection of problems taken from "standard" texts and college entrance examinations might be extended indefinitely. It is curious that authors and teachers alike seem to think that pupils want to know the answers to them. As a matter of fact, the pupils are, in the face of such problems, in very much the same quandary in which Mr. Dooley found himself when in the upper berth of the sleeping car. After pondering on "how a man could take off his clothes when he was sitting on them," he asks: "and what should I do with them when I got them off?" Finding no satisfactory answer to this question, he decided "to take off nothing but his hat." The pupils would surely be grateful if they could dispose of the question of what to do with the answers after they got them in so summary a manner as this.

It is clear that problems of the sort just given were made up to be problems in order to help the pupils in becoming familiar with the facts and principles of elementary physics. They correspond to no reality, and the difficulties involved in their solution, though introduced to give discipline, do not inspire the pupils with

an eagerness to gird themselves up to overcome them. They, therefore, give little transferable training. They are not very likely to inspire ideals of scientific method or respect for science. Fortunately, this type of problem is beginning to disappear from both texts and examinations.

119. Vital Problems Needed. — The questions and problems that are coming in to give the pupils practice in thinking and real discipline in overcoming significant difficulties are of the following kind: —

What is the correct position in dismounting from a moving street car? Why?

Why does an automobile tear up the surface of the road more than a team and wagon do?

Why do you stand in a moving car with your feet far apart?

Why are there doorknobs on doors?

When you shovel coal, do you pull up on the shovel with your left hand as hard or harder than you push down on its handle with your right? Why?

When you sweep a rug with an ordinary broom, does each hand do half the work? If not, show which hand does the more.

How much work do you do when you go up a flight of stairs 10 feet high?

When you come downstairs, do you get back the work done in going up? How?

Why does lowering the handles of a wheelbarrow make it easier to go over a bump?

Why do raindrops make inclined streaks on the windows of a railway car? In which direction do the streaks slope when the car is moving east?

If you weigh 125 pounds and can just float with your nose out in fresh water, what is your volume?

Could twenty-five horses make an automobile go as fast as a twenty-five horse-power engine can? Why?

What makes a wood fire snap and crackle?

Why can vegetables be cooked more efficiently in a fireless cooker than on a red hot stove?

What prevents a pond from freezing solid?

Which cools faster, a cup of hot tea or the tea that remains in the teapot? Why?

What is the dew point directly under the lid of a kettle of boiling water?

Why does the air escaping from the valve of a bicycle tire feel cool?

How many pounds of coal does your furnace burn daily? How many B. T. U. of heat are liberated in the house per day? How many foot pounds of energy does this represent?

Why can birds perch without harm on electric wires?

Why is the "third rail" dangerous, while the rails of an ordinary trolley track are not?

Can you light a Christmas tree with 6-volt lamps if the only current available is the 110-volt city current? How?

Why does clapping your hands make a noise while waving them does not?

Why should colors that are to be worn in artificial light be selected in the same kind of light?

Does placing a red shade over an alcohol flame colored with salt make people look less ghastly? Why?

What makes the colors in a soap bubble?

Why has no one ever found the pot of gold that lies buried at the end of the rainbow?

These are a few samples of the many questions which have some chance of defining significant problems for the majority of the pupils. When they have acquired some skill in the solution of such problems, it may be possible to make more abstract problems significant to them. Whenever this can be done, it is well to do it; but it is practically useless to begin with the abstract problems if the purpose of the instruction is that defined in Chapter IX.

120. **Ordinary Examinations Inefficient.** — Besides the questions and problems which form an almost daily part of the course, examinations and quizzes given by the teacher himself may be made of great importance both for the pupils and for the teacher. The ordinary form

of examination, however, in which the pupils try to answer questions and to solve problems is open to two serious objections. In the first place, it tests the pupil in too many ways at once. His answers are the combined sum of the activities of his memories, his observations, his past experiences, his present condition, and so on. In the second place, the evaluation of the pupil's paper by the teacher is subject to a large error due to the personal equation. The grades assigned by different teachers to the same papers differ widely. Also ability to answer examination questions is no sure mark of ability to think scientifically.

121. More Definite Tests. — For these reasons the teacher who wishes to test his own work in order to discover where he is failing and where succeeding will find the ordinary examination a rather fickle guide. He needs more definite and more quantitative measures of the progress of the pupils' abilities, and this measuring of the growth of human abilities is at best still an uncertain and precarious task, as Thorndike shows in his *Educational Psychology*. But notwithstanding the complexity of the problem, considerable progress has been made toward more definite methods of testing. Among these, Thorndike suggests the following:[1] —

[1] Thorndike, *School Science and Mathematics*, Vol. XI, p. 315, April, 1911.

"Knowledge may, however, be measured more conveniently than by the examination of notebooks, essays, or replies to questions of the ordinary sort. These have the merit of adequacy and richness, but the defects of measuring too many things at once and too indefinitely. Greater uniformity in the use of the test, quickness in scoring it, and freedom from ambiguity in the numerical value assigned can be secured by the exercise of enough ingenuity. I will mention two tests as samples of the many that are possible. The first is an adaptation of a test, devised by Ebbinghaus to measure mental efficiency in general, in filling in words omitted from a passage. From even the hastily devised sample presented here it will be seen that this form of test is scored with reasonable ease. The speed of an individual in selecting words to fill the gaps and the appropriateness of his selections together measure his knowledge. The former is scored with no effort at all and the latter with far less effort than is required to evaluate answers to questions, essays, or experimental work. The paragraphs and omissions therefrom should be arranged with care and improved after trial, but it may be of interest to some of you to compare the ratings obtained in six or eight tests of five minutes each like the following: —

"A body changing its position in space moves in a certain........... at a certain........A........in the

................called acceleration. To change either the................or the................of a moving ....requires................ Suppose a pound of lead to be held at rest 500 feet above the surface of the ocean by a string and the string to be cut. The body will............toward the............of the ....beginning to................with a ....of just barely over................ and reaching at the end of one second a................ of............feet from where it started. In one second the......... will have .... from ....to............feet per............

"The second is a very simple development of so-called association tests which I have used with good success in regular examinations in psychology for a number of years. It needs no explanation other than a sample.

"Write after each of these words some fact which it suggests to you: —

acceleration	gravity	current	lever
density	expansion	elastic	inclined

"As useful means of measuring the interests aroused by the study of science, I suggest records of the books taken from public libraries, of the periodicals chosen in public reading-rooms, of the collections gathered and objects constructed by pupils, and a modified form of the test

just described, the given words being much less easily provocative of thoughts about facts of science, and being mixed, if necessary, with words that would call up facts of science only in a person absorbed by scientific interests. The sample I give is left without such padding for disguise.

"Write after each of these words some fact which it suggests to you:—

work	time	wave	square
positive	light	level	change
water	rate	pull	book
mass	study	transform	gas
long	contract	heat	law

"This latter test of interest should be varied, using pictures of, say, a man rolling a barrel up a board into a wagon, a lightning flash in the sky, an ordinary balance scale, and the like, with a similar mixture of 'innocent' pictures. Besides words and pictures, actual or described events can be used. If such association tests are to be used to measure interest, they should not be used previously in the form calling definitely for facts about science. These tests of interests may be used to measure both special interests in particular sciences and general interests, as in fact rather than fiction, knowledge rather than opinion, or verification rather than dispute.

"Of other means of measuring the general changes wrought by the study of science I will mention only two. The first concerns the power to utilize experience well in thought.

"What is needed for this purpose is a series of problems or tasks, relative success with which depends as much as possible upon having power to use experience and as little as possible upon having had certain particular experiences. For example, relative success with the problem, 'Which is heavier, a pint of cream or a pint of milk?' is determined largely by ability to select in thought the essential fact that cream rises and to infer its obvious consequence. The data themselves are possessed adequately by all, or nearly all, pupils alike.

"To get such problems we wrote some time ago to one hundred teachers of science, half in universities and colleges, and half in secondary schools. I quote some of them: —

Raindrops are coming straight down. Will a car standing still or one moving rapidly receive in one minute the greater number of drops on its roofs and sides?

Is air drawn up a hot chimney or is it pushed up?

Since it is possible for a person to float in water why is it possible for him to sink?

A cylinder and a cone equal in base and in altitude rest on a plane surface. Which is harder to tip over?

A magnet attracts two iron nails. If the magnet is removed, will the nails attract each other?

Is it harder to keep your hands clean in the winter than in the summer? Why?

How many surfaces, corners, and edges has a cube?

Which has the greater surface, a cube 10 inches on edge or a sphere 10 inches in diameter?

What is the largest mammal in the world?

Does an iron ball weigh more when it is hot than when it is cold?

If a bottle of gas which is lighter than air be placed with its open mouth upward, will the gas escape from the bottle or will the heavier air press the gas back into the bottle?

Is an incandescent lamp filament on fire?

Will a ship that will just barely float in the ocean float on Lake Erie?

Will a pound of popcorn gain or lose weight or stay the same after it has been popped?

"The second means of measuring changes in general power to think is an adaptation of one devised by Professor R. S. Woodworth, in which the pupil picks out from such a series as that below the statements that are logically absurd, not possibly true. It will be seen that statements could be chosen which would test the power of analysis and of thinking things together in any field of

science from the most specialized to the most universal. Following is an example of this form of test.

Put a mark in the margin opposite each of the following sentences which is absurd:—

Though armed only with his little dagger, he brought down his assailant with a single shot.

Silently the assembly listened to the orator addressing them.

While walking backwards, he struck his forehead against a wall and was knocked insensible.

I saw his boat cleaving the water like a swan.

Having reached the goal, I looked back and saw my opponents still running in the distance.

Offended by his obstinate silence, she refused to listen to him further.

The one-armed cripple was attacked by a dog which seized his wrist, but he pushed it off with the other hand.

With his sword he pierced his adversary, who fell dead.

While threading my way through the crowd, I came suddenly upon an old friend.

The storm which began yesterday morning has continued without intermission for three days.

The dogs pursued the stag through flower gardens in full bloom.

That day we saw several icebergs which had been entirely melted by the warmth of the Gulf Stream.

While sharpening his three-bladed knife, my cousin cut his middle finger.

Our horse grew so tired that finally we were compelled to walk up all the hills.

The red-haired girl standing in the corner is taller than any of her older brothers.

A bricklayer fell from a new building quite near our house, and broke both his legs.

The hands of the clock were set back, so that the meeting was sure to close before sunset.

Many a sailor has returned from a long voyage to find his home deserted and his wife a widow.

The two towns were separated only by a narrow stream which was frozen over all winter.

"The great advantage of these means of measuring intellectual ability lies in their rapidity and ojectivity. If well devised, only two answers are possible, the pupil is measured easily, rapidly, and independently of subjective factors, and his condition is defined in terms of a simple numerical value.

"There is no time for me to discuss methods of making, recording, and utilizing these or the hundreds of other equally worthy measurements of educational achievement, that is, of changes produced or prevented in human nature. Nor is this a proper occasion to outline the precautions that are required by the complexity and

variability of facts of intellect and character and the absence of well-defined scales with equal units and known zero points, in which to measure facts of intellect and character. For our present purpose it is enough to know that, in spite of difficulties, the measurement can be made, and that a man of science can, if he will, be as scientific in thinking about human beings and their control by education, as in thinking about any fact of nature."

Another effective form of test consists in presenting to the pupils a simple experiment, and asking them to write brief answers to the questions: I. What was done? II. What happened? III. How do you interpret your observations? The teacher makes out a list of the points that are important to observe and of the justifiable interpretations. The papers are graded by counting the number of these points correctly observed and inferred by the pupil. For example, the teacher's statement of a perfect paper might be:—

I. An empty drinking glass was inverted and pushed down into a large beaker half full of water.

II. The level of the water was lowered inside the drinking glass and raised outside of it.

The level inside was slightly above the rim of the drinking glass.

III. Air is a substance that occupies space.

The pressure on the air inside the glass was increased by an amount measured by the difference in level between the water surface inside and that outside.

The air was compressed by this increase of pressure.

If a series of fifteen tests of this sort were given throughout the year, a teacher could get a fairly definite measure of the progress of each pupil in powers of observation, analysis, and inference. The value of such a series would be vastly increased if a group of fifteen or twenty teachers would coöperate in planning the series, in deciding which are the essential points of each test, and in grading the papers. If the superintendents of schools in large cities would encourage the physics teachers under their care to organize and carry out such a series of tests each year, the results would be of vastly greater educational value than those now obtained by supervision and the ordinary form of written examination.

122. **Tests Help the Teacher.** — The results of this kind of tests are also illuminating to the teacher. We all assume that pupils see in our experiments the points we intend to illustrate. This is by no means the case. These tests give us a very direct means of finding out what pupils do observe and how they do reason; and it is this information that is most needed at present to enable us to organize courses adapted to the abilities of the pupils. Our chief efforts in the past have been directed

to devising ways and means of making children swallow a logically determined body of knowledge called the facts and principles of elementary physics. Our present problem is, (1) to find out how the pupils actually do observe and think, and (2) to discover by experiment how the material of physics may be used most effectively to develop ideals of scientific method while acquiring a mastery of the most useful physical principles.

123. **Summary.** — The conclusions to which the discussion of the preceding pages point may be stated as follows: 1. The "faculty psychology" with its doctrine of formal discipline has been shown to be inadequate because of its neglect of the emotional factors of conduct. 2. Educational theory has progressed to the point where it is able to offer a fairly definite set of working hypotheses for democratic education. 3. The time has therefore come to test these working hypotheses by careful experimentation in classes under normal school conditions. 4. Such experimentation requires the coöperation of groups of teachers, and a more definite testing of results than is possible by the ordinary form of written examination. 5. This much-needed experimentation should be directed to solving two problems, namely, what material from physics is most effective for purposes of general education, and what is the most effective way of presenting and using that material?

124. More Efficient Teaching Demands Educational Experiments. — The supremacy of the classics and mathematics in the school world is due in large measure to the long process of refinement to which the methods of teaching them was subjected during the centuries in which they formed the mainstay of aristocratic schooling. These methods were perfected by a lengthy process of trial and error, and are fairly well adapted to the homogeneous class of professional men for whom they were devised and to whose professional interests they are closely related.

Correspondingly efficient methods of teaching the subjects that have recently been added to the curriculum, in response to the demands of democratic education, have not yet been devised. The students of to-day are no longer parts of a relatively homogeneous class, but make up an extremely heterogeneous mass with widely diversified interests, motives, and needs. Their demands are insistent and pressing, so there is not time to develop the methods of teaching the newer subjects, of which physics is one, by the long process of trial and error used in the case of the classics.

The remarkable progress made by the science of physics in the last twenty-five years is due in large measure to the ever increasing amount of laboratory work that has been done. In like manner, we may look

for an accelerated progress in methods of teaching physics as soon as physics teachers begin a laboratory study of their methods of teaching. As in physics, so in education, the first essential for efficient laboratory work is a system of suitable units and methods of measurement. Such a system cannot be established without a vast amount of labor and a generous coöperation among those who are working for its establishment. If this book shall be the means of arousing some physics teachers to the nature and the immediacy of the problem before us, and of stirring them to devote some attention to the laboratory study of this problem, its purpose will be fully accomplished.

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INDEX

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